

Rotating Equipment Operating Outside Intended Design Life and Usage Parameters

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Declaration of Authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

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Date:

Abstract

Sem Logistics operates by storing a range of petrochemicals for third parties, i.e. Light Crude oil, Gas oil, Kerosene, Gasoline, Alkylates and other Crude oil derivatives.

Figure 1 – Sem Logistics Milford Haven



There are fifty-two storage tanks at the facility, making it the largest site of its type in the UK, accounting for almost one quarter of the UK's independent hydrocarbon storage, (Sem Logistics, 2015).

The site is able to offer large product movements operating within Milford Haven, one of the deepest naturally occurring havens in the world, allowing vessels up to 165 thousand tonnes to berth.

The quantity of hydrocarbon stored at Sem Logistics makes it a top tier site under Control of Major Accidents and Hazards 1999, (COMAH); subject to scheduled and unscheduled visits by the government appointed enforcing agency of the Health & Safety at Work act, (HASAWA (1974), known as the Health and Safety Executive, (or HSE).

The nature of the site requires maintenance strategies to be continually developed, aimed at minimising instances of hydrocarbon containment loss, and better predicting when a piece of equipment is at risk of failure.

Much of the equipment at the site is approaching fifty years in service and hence falls under the category of ageing plant, meaning the maintenance regimes and methods in which it is proven to be safe to use are closely scrutinised.

Shortcomings were perceived in mechanical equipment maintenance management, and an investigation was undertaken to determine whether condition monitoring methods implemented on equipment operating outside the intended design life were sufficient.

Failure modes were identified and the manner of addressing these together with the maintenance of ageing plant is discussed.

The 'COMAH Competent Authority; Ageing Plant Operational Delivery Guide' and 'EEMUA; The mechanical integrity of plant containing hazardous substances' guides were used to model the way in which maintenance is performed, logged and bettered.

In addition, much of the equipment at the site was now subject to longer and more frequent periods of dormancy since the transition from refinery to storage facility.

In order to prove the fitness for service of the ageing equipment a number of changes were implemented to maintenance and data logging with effect January 2013.

The following topics are to be expanded upon throughout the course of this report:

- Intrusive data gathering methods implemented on hydrocarbon pump sets
- Non-intrusive data gathering methods implemented on hydrocarbon pump sets and tank agitators
- Sporadic equipment use challenges and the modifications made to pumps and agitators to lessen chance of inactivity related failure modes becoming effective
- Modernisation of centrifugal pumps which includes the installation of a double mechanical sealing arrangement on the highest risk pump sets
- Modernisation of tank agitators complete to lower risk arrangement more capable of dealing with the sites usage parameters
- Documenting of mechanical seal failure rates on pumps and agitators allowing better prediction of when seal failure may occur
- The progression of the condition monitoring, data logging and modernisation of equipment going forward

Engineering function at the Site

A wide range of mechanical equipment is used at Sem Logistics comprising of; ship to shore connective loading arms, permanently mounted lifting arrangements responsible for the suspension and movement of the loading arms, mechanical pressure relief valves, a range of valve types of differing size and manufacturer, and centrifugal pumps and tank agitators categorised as 'rotating equipment'.

The most significant risk to uncontrolled hydrocarbon release are the pipelines and tanks themselves, where failure has the potential to lead to major environmental disaster categorised in tons of spillage.

The next most significant contributor to this risk is mechanical equipment housing hydrocarbons, rotating equipment falling into this category. Historical failure rates showed such uncontrolled hydrocarbon releases through rotating equipment failure were quite common.

Although not considered large releases in most instances, the additional risk that rotating equipment poses is that the energy generated through the rotation leads to an elevated fire risk, which has the potential to escalate the threat from such failures to a higher level.

In order to prevent and minimise mechanical failures at the site, the following measures are taken:

- Ensure creative and innovative invasive & non-invasive techniques are used to gather information on the condition of all equipment, with particular emphasis on ageing plant condition monitoring methods.
- Application of the trending of data to better evaluate when a failure may occur and take steps to lessen likelihood, based on prior failure rates, thickness loss and wear rate/dimension analysis.
- The maintenance engineer must proactively research, maintain awareness and optimise new and emerging technologies, materials or processes to benefit the company in regard to demonstrating a proactive approach culture is taken in all areas of maintenance at the site.
- Occurrences of uncontrolled hydrocarbon containment loss must be minimised, and an approach must be taken that constantly looks to improve the sites equipment failure rates.
- Engineering problems seen at the site must be overcome by initiating design studies, research and inhouse production of specification for the introduction of new equipment to the site, or the retrofit of components/systems to existing plant.

Aims and Objectives of the Project

The purpose of performing the maintenance and data logging depicted throughout the course of this report is to demonstrate that:

- Prove all reasonably practicable steps have been taken in ensuring that the rotating equipment in service at Sem Logistics is safe to use
- Detail the maintenance performed to allow easy presentation whilst under scrutiny from a third party whether that be; superiors within the company, colleagues, for the purposes of comparison and bettering the method in which they perform their duties, or any other body with the authority to question the sites strategies, such as the HSE
- Highlight the methods in which the ageing equipment at a top tier COMAH regulated site should undergo extensive condition monitoring and failure pre-emption, for the purposes of lessening uncontrolled hydrocarbon release
- Aim to prove that although much of the plant is approaching fifty years in service, that in most cases its removal from service is not necessary based purely on its age
- It will be demonstrated that although most likely operating outside its intended design life, if the correct methodology is followed, plant should not fail due to this factor alone in the usage conditions seen at the site
- Expand on the modernisation of plant components to suit the differing conditions such as sporadic usage and range of product service seen since operating as a storage facility
- Where component upgrade or redesign is not deemed appropriate, cases of equipment renewal complete are to be detailed
- The objectives detailed above are to be based on a four-year period at the Sem Logistics from January 2013 to present day, during which time there were drastic improvements in the approach taken to maintenance, data logging and failure pre-emption as a whole

Timing Plan

- January 2013 – April 2016 – Extensive data gathered on rotating equipment condition and failure rates gathered, prompted by HSE site visit in December 2012 which found shortcomings in maintenance approach to ageing plant
- 01/07/16 - Official dissertation start date, proposal drafting commenced
- 27/09/16 - Proposal hand in date – deemed an appropriate topic for report
- 16/12/16 - Interim viva presented detailing target areas of report
- 17/12/16 - 28/4/17 - Main body of dissertation to be compiled

Literature review

The following literature was used as a basis for developing the maintenance strategies targeted at ageing plant in use at Sem Logistics.

'COMAH Competent Authority: Ageing Plant Operational Delivery Guide'

COMAH – Control of Major Accidents and Hazards.

Being a COMAH publication, the information available from this guide proved to be of significant use, detailing the target areas that maintenance of ageing plant would be scrutinised on.

(Ageing Plant Operational Delivery Guide, 2010): “1.1 This Delivery Guide (DG) underpins the Competent Authority’s programme to prevent, control and mitigate major accidents at COMAH sites; it does this by ensuring ageing mechanisms which could cause plant deterioration and increased major hazard risks are recognised and are being managed effectively...Ageing mechanisms such as corrosion, erosion, fatigue, obsolescence and calibration failure should form part of a site’s asset integrity management system...In practice, ageing plant issues may be best tackled as part of overall inspection plans related to asset integrity management.”

It can be found that there are a large number of similarities in the ageing plant maintenance methods now implemented at Sem Logistics when compared to this guidance, as they were specifically designed to meet the target areas detailed.

'EEMUA: The Mechanical Integrity of Plant Containing Hazardous Substances'

EEMUA - Engineering equipment and material users association.

Whilst not targeted at ageing plant specifically, this guide detailed methods in which the integrity of equipment housing hazardous substances should be challenged and proven.

(EEMUA231, 2012): “The Health and Safety Executive (HSE) considers maintenance of the integrity of plant containing hazardous substances to be a fundamental element of good process safety management.”

Interpretation of this guide highlighted the necessity of appropriately assessing the potential hazard severity of uncontrolled release of hydrocarbon, and highlighted the importance of minimising such occurrences.

HSE: 'Management of equipment containing hazardous fluids or pressure'

This report specifically gave guidance to individuals and organisations responsible for the maintenance and inspection of equipment containing hazardous fluid or pressure.

(RR509 - Plant ageing: Management of equipment containing hazardous fluids or pressure, 2006): "The purpose of this report is to increase awareness of the factors to consider when managing equipment containing hazardous fluids or pressure, and to help those responsible for equipment to understand and assess the risks of accumulated damage and deterioration. The information is at a general rather than an equipment-specific level, and can be applied to a wide range of static equipment and associated machinery."

Targeted specifically at ageing plant, the report was designed to help develop appropriate methods of maintaining equipment in a manner which helped to ensure its integrity was not compromised.

'API 610 – Pump Standard Guidelines'

API – American Petroleum Institute

API was referenced when deciding upon maintenance strategies as it was the guide used to base the specification of the majority of pumps in service at Sem Logistics.

Although API 610 was written prior to the topic of ageing plant becoming a major consideration when deciding on maintenance strategies, such guidance could be used to assess whether the pumps were still meeting their initial specifications after decades in service.

This was the case in regard to the wear ring clearances documented throughout the intrusive data gathering performed during the report.

(API610, 2001): "Radial running clearance shall be used to limit internal leakage...renewable wear rings shall be provided within the pump casing. Impellers may have integral wear surfaces or renewable wear rings."

The wear ring clearances found were used as a basis to make an educated assumption that as this area of the pump was not found to have excessive wear, as the highest wearing area of the pump set showed minimal signs of degradation, that the other pump components although not as easily measurable were most likely not excessively worn either.

Table of Contents

Abstract.....	1
Figure 1 – Sem Logistics Milford Haven	3
Engineering function at the Site	5
Aims and Objectives of the Project.....	6
Timing Plan.....	6
Literature review.....	7
1.0.0 - Data Gathering Methods	13
1.1.0 - Intrusive Pump Condition Data Collection.....	13
1.1.1 - Figure 2 – A Typical Centre Hung Centrifugal Pump Used At Sem Logistics.....	14
1.1.2 - Areas Targeted During Pump Refurbishment & Data Collection.....	14
1.1.3 - Wear Ring Clearances	15
1.1.4 - Figure 3 – Wear Ring Location within Pump Set.....	15
1.1.5 - Figure 4 – Closer View of Wear Ring Area	15
1.1.6 - Figure 5 - Impeller Wear Ring Measurement in Progress.....	16
1.1.7 - Table 1 – API 610 Recommended Wear Ring Clearances.....	16
1.1.8 - Table 2 – Wear Ring Dimensions taken During Pump Refurbishment	16
1.1.9 - Impeller Wall Thicknesses.....	17
1.1.10 - Figure 6 – Impellor Wall Thickness Measurement in Progress.....	17
1.1.11 – Table 3 – Impellor Wall Thickness Measurements	17
1.1.12 - Wear Ring Dimension Analysis	18
1.2.0 - Non-Intrusive Data Gathering Methods	19
1.2.1 – In Service Data Gathering Methods	19
1.2.2 - Vibration Analysis	19
1.2.3 - Figure 7 – Condition Monitoring Overview	20
1.1.13 - 21G87X Bearing Defect Verification	21
1.1.14 - Figure 8 - Drive End Bearing.....	21
1.1.15 - Figure 9 – Outer Race Visible Defect	21
1.1.16 - Figure 10 – Ball Bearing Visible Defects (also highlighted in survey)	22

1.1.17 - Figure 11 – Vibration Survey Extract - Harmonics	22
1.2.4 - Remote Vibration Monitoring & Analysis	23
1.2.5 - Figure 12 – Remote Vibration Data Transmitted to Web	23
1.2.6 - Ultrasonic Thickness Measurement Regime.....	24
1.2.7 - Initial Problems with UT Data Collection	24
1.2.8 - Figure 13 – Thickness Measurement Location, (TML), markers	24
1.2.9 - Figure 14 – Graph 1 - Pump Set UT Graphing	25
1.3.0 - Limitations of 90° Probe Ultrasonic Thickness Measurement Inspections	26
1.3.1 – Figure 15 – Volute Casing Defect Location	26
1.3.2 – Casing Irregularity Investigations	26
1.3.3 - X-Ray of Casing Wall	27
1.3.4 - Fig 16 - X-Ray Image of Casing Wall	28
1.3.5 – Shear Wave UT Inspection of Casing.....	28
1.3.6 - Fig 17 – Shear Wave Inspection Interpretation of X-ray.....	28
1.3.7 – Analysis of X-ray & Shear Wave NDT	29
1.3.8 – Cost saving to The Company	29
1.3.9 – Thermography.....	30
1.3.10 – Figure 18 – 21G87X Non-Drive End Thermographic Imaging	30
1.3.11 – Figure 19 – 21G87AX Non-Drive End Thermographic Imaging	30
2.0.0 - Sporadic Usage Related Findings	31
2.1.1 – Pump Modification for Sporadic Usage	31
2.1.2 - Figure 20 – Seal Running Area	31
2.1.4 - Figure 21 – Chrome Oxide Coated Shaft.....	32
2.1.5 - Figure 22 – Graph 2 - Pump Seal Failure Graphing	32
2.1.6 - Tank Agitator Modification for Sporadic Usage & Multi Product Use.....	33
2.1.7 - Figure 23 – Belt Driven Tank Agitator GA	33
2.1.8 – Agitator Mechanical Seal General Arrangement	33
2.1.9 - Figure 24 – Mechanical Seal General Arrangement	34

2.1.10 - Rubber Component Incompatibility for Multi Product Service	34
2.1.11 – Seal Face Material Failure Due to Inactivity.....	35
2.1.12 - Changes to Rubber Components – Post PDS & FMEA	35
2.1.13 - Changes to Seal Face Materials	36
2.1.14 Figure 25 – Carbon Graphite Properties	36
2.1.15 - Figure 26 – Silicon Carbide Properties	36
2.1.16 - Change in Seal Face Design – Stepped RSF	37
2.1.17 – Figure 27 - Stepped RSR	37
2.1.18 - Pressure within sealing system calculations.....	37
2.1.19 - Figure 28 – Graph 3 – Hydraulic Balance Stepped RSF vs Non-Stepped	38
2.1.20 - Conclusion of hydraulic balance calculations	39
2.1.21 - Figure 29 – Silicon Carbide Compressive Strength & Wear Properties	39
2.1.22 - Figure 30 – Carbon Graphite Compressive Strength & Wear Properties	39
2.1.21 – Evaluation of Mechanical Seal Changes on Agitators	40
2.1.22 – Figure 31 – Agitator Seal Failure Upgrade & Failure Logging	40
2.1.23 – Figure 32 – Graph 4 - Agitator Seal Failure Graphing	40
3.0.0 – Upgrading of Equipment to Modern Standards	41
3.1.1 - Double Mechanical Seal Retrofit Summary	41
3.1.2 – Figure 33 – 53A Design Mechanical Sealing Arrangement	42
3.1.3 – Figure 34 – Fitment of Upgraded Sealing Arrangement in Progress	43
3.1.4 – Figure 35 – Pump Relocated in Situ	43
3.1.5 - Initial Test Run Findings	44
3.1.6 - Secondary Extended Test Run & Commissioning of Unit	44
3.1.7 – Replacement of Agitators with New Equipment Complete.....	45
4.0.0 – Results - Summary of Report	45
Discussion and Conclusions	46
Recommended Further Work	49
Further Agitator Maintenance and Condition Monitoring	49

Further Pump Maintenance and Condition Monitoring.....	50
Further Changes to Maintenance if Site Usage Changes.....	50
Bibliography	51
Appendices.....	53

1.0.0 - Data Gathering Methods

Reliability improvement and condition monitoring methods are applied to all mechanical equipment at the site, this report focuses on the methods implemented on rotating equipment only.

The rotating equipment in use at the site comprises of; centrifugal hydrocarbon pump sets of centre hung or over hung construction, (shaft supported either end by bearing races or one end only respectively), and tank agitators of differing manufacturer, size and design.

1.1.0 - Intrusive Pump Condition Data Collection

Where possible during data collection, manufacturer's inspection guidelines were referenced and used to focus work.

The maintenance guidelines available stated that a 'drop in pressure against reading when the pump was new indicates excessive clearances in the pump'. As information on the pumps outlet pressure when new was not available, the areas targeted through this data collection were deemed to be the most representative of the units ability to pump effectively, and were gathered in a repeatable manner.

The capturing of this data at a point in time, meant future re-measurement would allow a wear rate to be established, and in turn a resulting inspection frequency.

The regime has enabled inspection frequencies to be determined and prediction of lifetime of the pump and individual components fitness for service.

This intrusive data collection commenced in 2013, first targeting units that had issues such as; lower than expected performance, evident external corrosion and in some cases minor seal leakage. This approach was used as a basis for all such future inspections.

To allow such data collection to be carried out, the units were removed complete from situ and moved to the workshop to undergo full refurbishment.

During refurbishment, all major pump components were removed and separated for their condition to be assessed.

Centre hung pumps comprise a central shaft mounted impellor, suspended between a bearing race support either end of the shaft, relying on a mechanical seal on both ends of the casing to separate the internal pressure generated within the pump from atmosphere.

1.1.1 - Figure 2 – A Typical Centre Hung Centrifugal Pump Used At Sem Logistics



Removal of the unit from situ to the main workshop allowed strip down to be carried out in an environment where factors such as weather, cleanliness and other operations at site did not affect the reliability or quality of the measurements gathered.

1.1.2 - Areas Targeted During Pump Refurbishment & Data Collection

The following areas were specifically targeted during strip downs and subsequent data gathering, as they were considered the most representative of condition and ability to pump effectively, hence addressed the manufacturers guidance.

Periodical future inspection of the following allowed a wear rate to be established:

- Wear ring clearances comparison to API 610 standards
- Impellor wall thickness assessment & condition assessment

All components were visually examined to highlight any defects that were deemed to be age related, or if there were signs of the development of failure modes that had either become, or had the potential to become effective due to periods of inactivity.

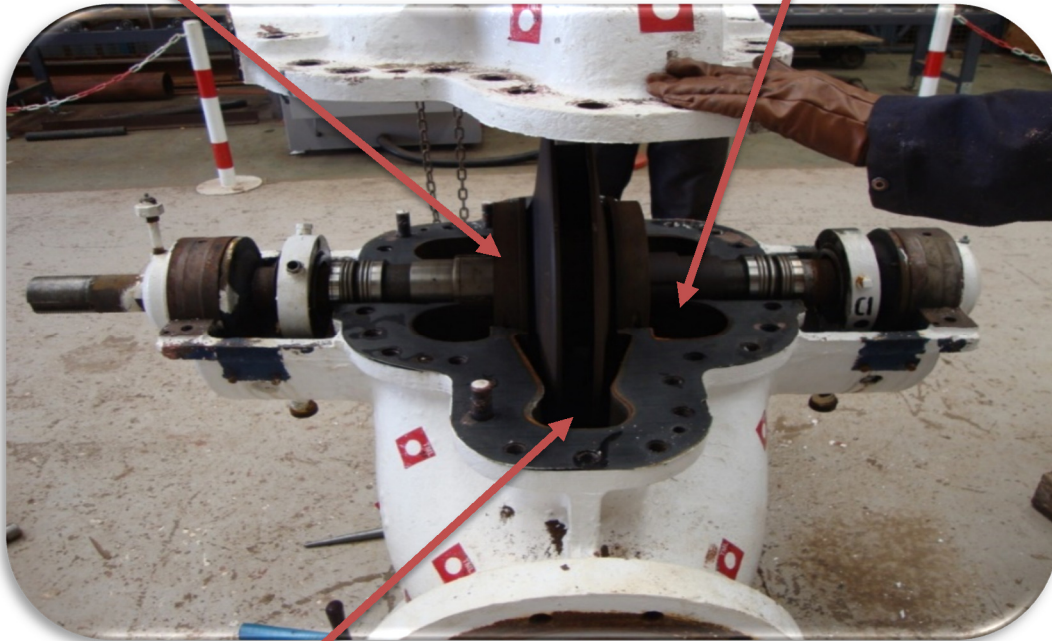
1.1.3 - Wear Ring Clearances

Drive end, and non-drive end wear ring clearances – wear rings are an area of the pump that separate the low and high pressure side of the pumping process.

1.1.4 - Figure 3 – Wear Ring Location within Pump Set

Wear ring area

Low pressure inlet area

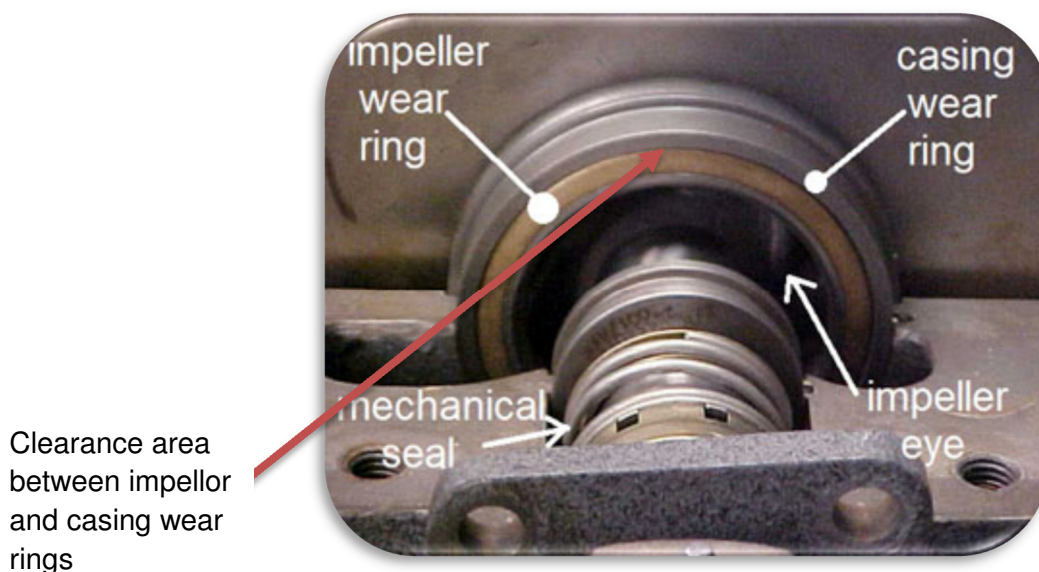


High pressure outlet area

A closer view of this area can be seen in figure 4, image taken from (Tistory, 2017):

The outer or 'casing wear ring' pictured below is fixed in position within the pump casing, within which the impeller wear ring turns, fixed to the impeller:

1.1.5 - Figure 4 – Closer View of Wear Ring Area



Clearance area
between impellor
and casing wear
rings

1.1.6 - Figure 5 - Impeller Wear Ring Measurement in Progress



1.1.7 - Table 1 – API 610 Recommended Wear Ring Clearances

Wear Ring Diameter in Inches	Minimum Diametrical Clearance Recommended by API 610 Standards, (in inches)
1 - (Anything under 2" diameter has same minimum clearance by API 610 standards)	0.010
10.000 - 10.999	0.021
11.000 - 11.999	0.022
12.000 - 12.999	0.023

The dimensions taken were then compared to the recommended clearances depicted with API 610 guidelines:

1.1.8 - Table 2 – Wear Ring Dimensions taken During Pump Refurbishment

Inner impellor wear ring (D.E)	Pump body wear ring	Diametrical clearance	Comments
11.000"	11.025"	0.025"	Above process pump minimum tolerance, see below chart.
Outer impellor wear ring (N.D.E)	Pump casing wear ring	Diametrical clearance	Comments
11.000"	11.025"	0.025"	Above process pump minimum tolerance, see below chart.

1.1.9 - Impeller Wall Thicknesses

Readings were taken from the centre of each impeller vein and compared to highlight any loss in thickness drastically higher than the neighbouring vein, this measurement was also averaged to give an overall thickness value for the drive end, (D.E), and non-drive, (N.D.E), of the unit in question.

Thickness readings were taken in the centre of each vein, on either side of the impellor.

1.1.10 - Figure 6 – Impellor Wall Thickness Measurement in Progress



1.1.11 – Table 3 – Impellor Wall Thickness Measurements

Drive End		Non-Drive End	
Measurement point	Thickness	Measurement point	Thickness
1	0.412"	1	0.427"
2	0.336"	2	0.429"
3	0.431"	3	0.413"
4	0.411"	4	0.395"
5	0.380"	5	0.418"
Average thickness 0.394"		Average thickness 0.416"	

On the unit pictured, impellor wall thickness had not been documented in previous overhaul works, meaning it was difficult to draw a conclusion on wear rate in this area.

Future re-measurements would allow a trend to be established and a resulting future inspection frequency of this area to be set.

1.1.12 - Wear Ring Dimension Analysis

The 'drive end' and 'non-drive end' of the unit will be referred to the D.E and N.D.E respectively.

Comparisons were taken during such investigations depicted above against the API 610 guidelines, and in most cases, it was found that the diametrical clearances, D.E & N.D.E, were above the lowest allowable tolerance.

Maintenance reporting prior to 2013 was sporadic, although historical records that were available were found to show anything from 0.000" - 0.006" diametrical clearance over the previous decade.

Although there are no maximum wear ring tolerances specified in API 610, wear rings are normally renewed if diametrical clearance doubles the minimum, (McNally Institute, 2017) "you lose 1% pump capacity for each 0.001" of wear"

Based on typical wear rates, it was found that the majority of units that underwent intrusive data collection were not due to reach double the minimum clearance for another 60 years in service.

By its design, this area is the highest wearing location within the pump set, therefore the typical wear rates found allowed the conclusion to be drawn that insignificant wear in this area proved insignificant wear to the other pump internals, helping to justify the continued use of such ageing equipment at the site.

Although the centrifugal pumps were fifty years old, the wear ring and impeller dimensions taken and analysed, coupled with the visual inspection of all other components, meant that there was no viable reason to retire them from service based on their internal wearing component degradation rates and age alone.

Such investigations helped to demonstrate that a pro-active approach was being taken to gathering in depth information on ageing equipment in use at the site, and helped justify its continued use.

1.2.0 - Non-Intrusive Data Gathering Methods

As well as the intrusive data gathering methods documented, such removal was not always possible due to equipment demand for continuity of the sites operation, therefore a number of non-intrusive data collection methods were implemented at the site.

1.2.1 – In Service Data Gathering Methods

The following methods would target the units that awaited refurbishment and intrusive data collection, and help justify their use in the interim:

- Vibration Analysis
- Ultrasonic thickness inspections
- Thermography

Non-intrusive methods are sometimes seen as best practice due to statistical information that equipment is most likely to fail catastrophically following major works. (Casey, 2005) “Incorrect commissioning during startup can result in damage...through cavitation, aeration and inadequate lubrication...this damage will not show itself until the component fails.”

1.2.2 - Vibration Analysis

Vibration analysis is a widely used non-intrusive data collection method implemented on rotating equipment, the data collected can be used to identify a range of problems. (SKF, 2017) “method of predictive maintenance to extend machine service life and prevent unplanned shutdowns”.

Certain vibration frequencies or characteristics can be analysed, the analysis of the data is then performed, (SKF, 2017) “Conditions that can be detected before they cause machine breakdown are;

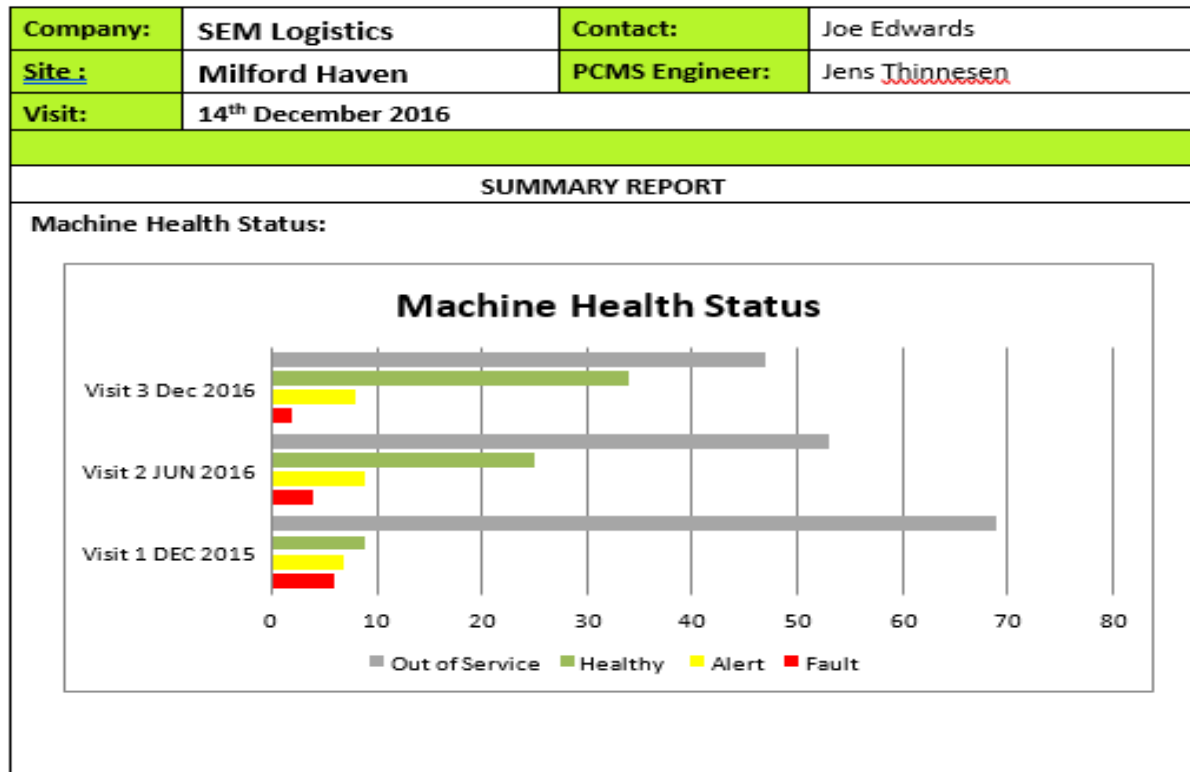
- Misalignment
- Out of Balance
- Mechanical looseness
- Poor lubrication
- Bearing damage”

A six-monthly survey regime was implemented on all available equipment, highlighting any rotating equipment defects requiring immediate attention, and giving a trackable insight into the degradation rate of equipment over time.

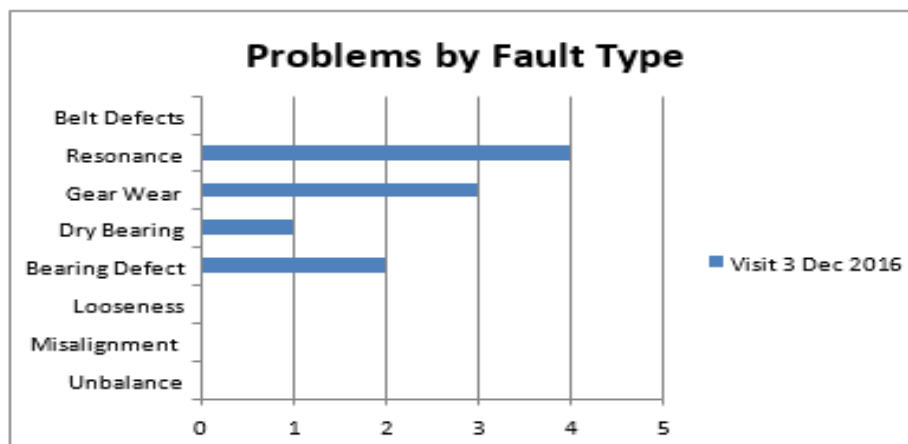
Following the third survey, this data was graphed, providing a visual representation of the condition of rotating machinery in use at the site, see Figure 7.

1.2.3 - Figure 7 – Condition Monitoring Overview

1. Condition Monitoring Overview



Problem Type:



Due to a large number of the tanks at the site having undergone major refurbishment work, more rotating equipment was available for the data gathering to be performed.

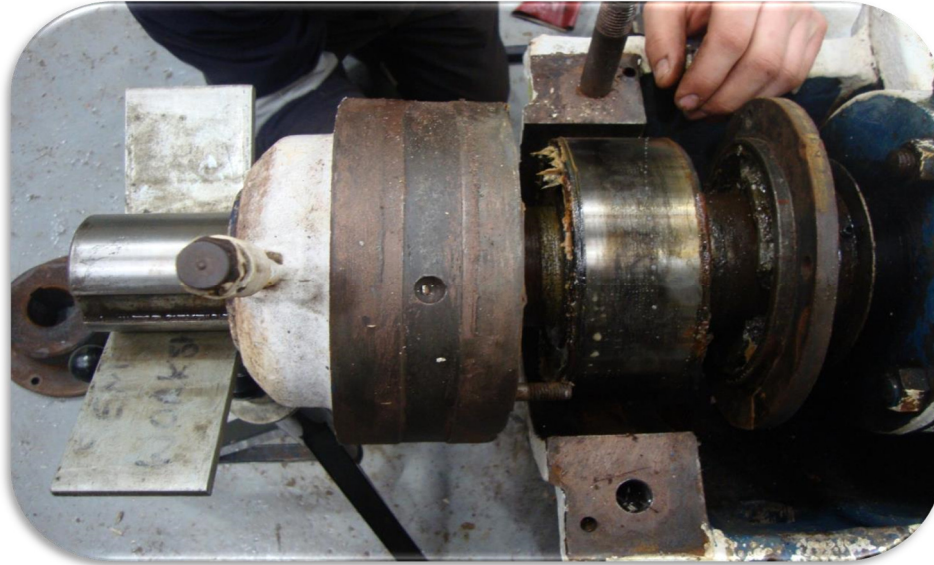
The information gathered and depicted in figure 7 shows an improved percentage of equipment in service versus in alert or fault status. This was attributed to rectification of defects being performed as soon as was reasonably practicable, such as '21G87X Bearing Defect Verification' prompted by this survey.

1.2.4 - 21G87X Bearing Defect Verification

Additional intrusive investigations were also carried out during pump refurbishments if deemed necessary.

The following was performed as a result of a condition monitoring surveys such as earlier depicted, for the purposes of verifying the information provided as correct, and hence help prove its accuracy as a meaningful non-intrusive data collection method.

1.2.5 - Figure 8 - Drive End Bearing



The drive end bearing of the unit in question was removed and cut open and cleaned, upon close visual inspection, signs of outer bearing race condition breakdown were found:

1.2.6 - Figure 9 – Outer Race Visible Defect



Visible outer race condition breakdown.

1.2.7 - Figure 10 – Ball Bearing Visible Defects (also highlighted in survey)



1.2.8 - Figure 11 – Vibration Survey Extract - Harmonics

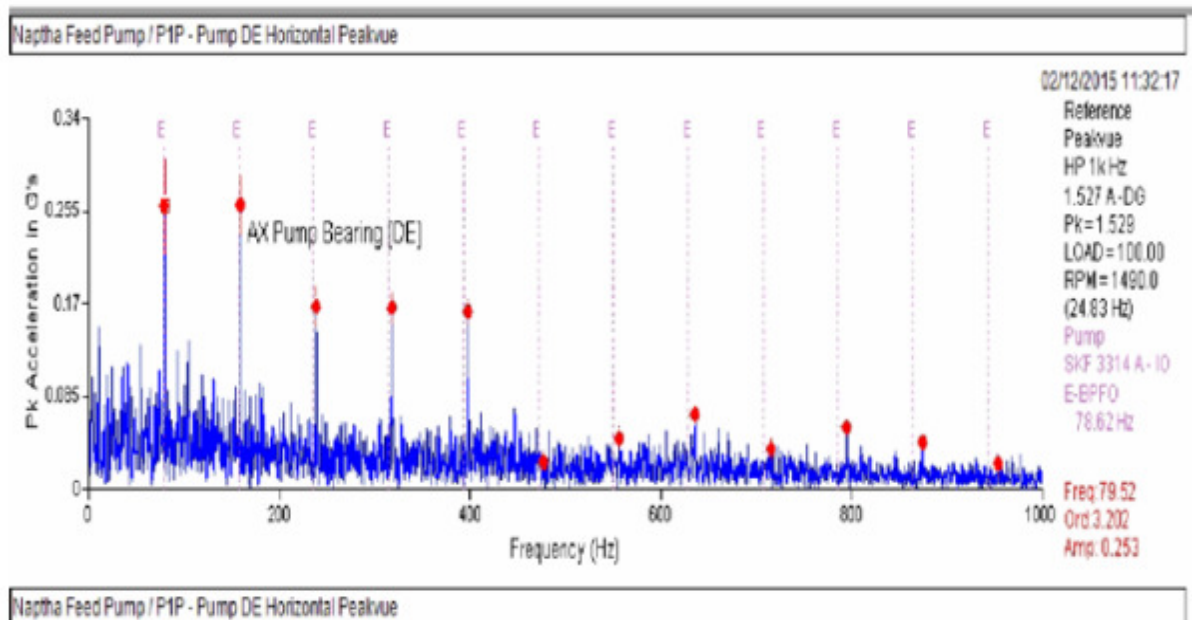


Figure 11 analysis showed evidence of high levels of harmonics present, harmonics have proven to be associated with outer bearing race defects, (Electromotores, 2003) elaborates: “If the frequency and harmonics (multiples) of it are present are on the vibration spectra, you most probably have an outer race bearing defect....a spall on the raceway, electrical fluting, false brinelling acquired during bearing storage or equipment transfer”.

This investigation verified the vibration data gathered, and justified it as a reliable non-intrusive data collection method.

Following such verification, it was decided that there was a benefit to installing a remote vibration monitoring system on the most used pumps at the site.

1.2.9 - Remote Vibration Monitoring & Analysis

As vibration monitoring had been deemed an accurate and useful tool in the sites on-going maintenance improvement approach, a remote vibration monitoring system was installed on the unit that had undergone the intrusive bearing defect investigation above, as it was one of them most run pumps on site.

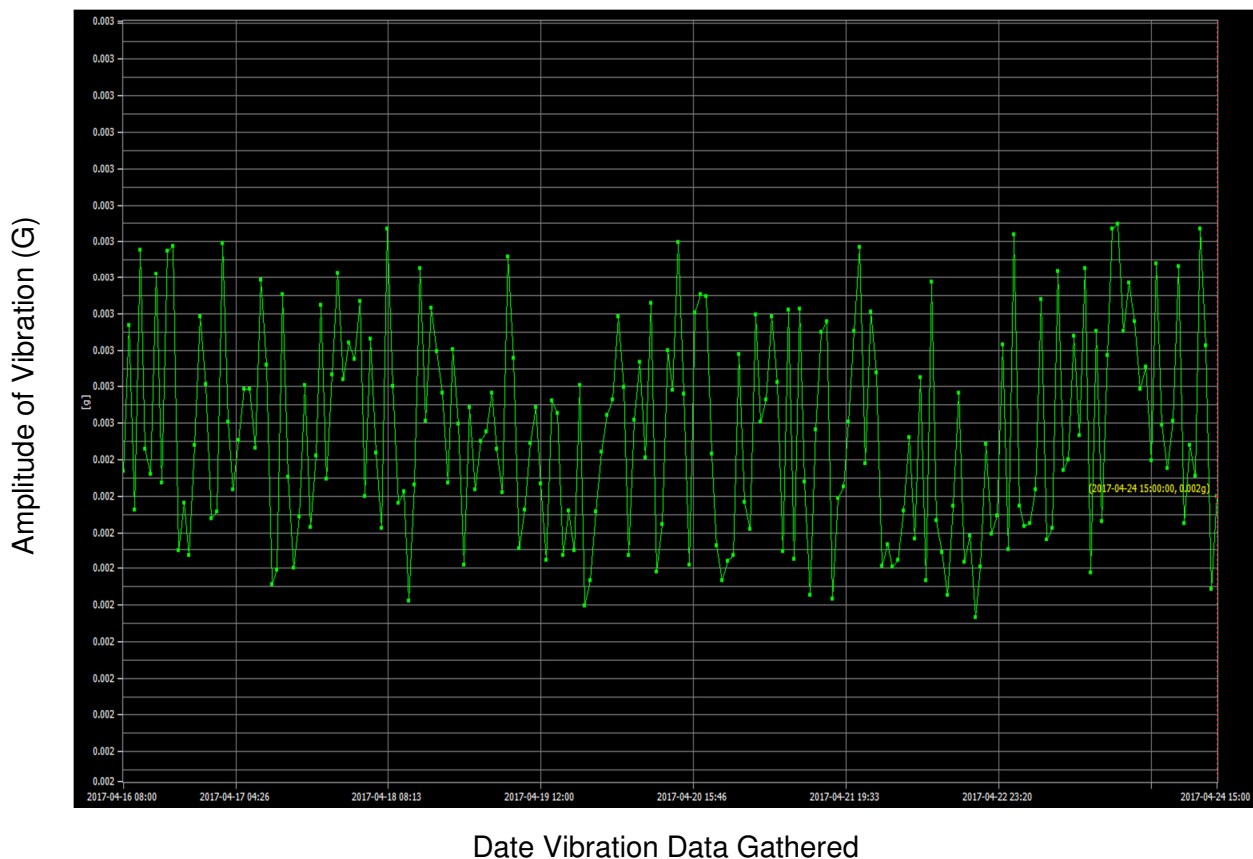
This system was one of the first systems installed in the UK that would transmit straight to a web based server. The data could either be analysed by Sem Logistics as the client, or was easily viewed by a third party and consultancy provided on the unit's condition based on the data if required.

Whilst still in its trial period at the site, the information received to date is proving very useful as it is gathering information during every running period, meaning that an exact bearing degradation rate can be determined.

This bearing degradation rate will then be used to make a prediction on the likely bearing degradation rate of lesser run pumps at the site, and help to set a future inspection frequency going forward for all other bearing renewal frequencies.

1.2.10 - Figure 12 – Remote Vibration Data Transmitted to Web

The below data can now be trended to establish an exact degradation rate.



1.2.11 - Ultrasonic Thickness Measurement Regime

Ultrasonic thickness measurement has been in use for many years in industry, (Nelligan, 2017) states “for a wide variety of test applications became common in the 1970s”, and is known as a very effective non-destructive or intrusive means of gathering thickness data.

Whilst in use at the site in a range of other applications such as storage tank wall, floor and roof data collection, it had not been used to gather data relating to pumps and the equipment associated with them.

It was not known whether the measurements gathered would yield meaningful data, hence a trial was commenced on all in service hydrocarbon pump sets at Sem Logistics.

The aim of the investigation was to gather information on the average casing thickness loss per year due to the pumping process, and predict when a pump should be retired prior to reaching a point where it may not be capable of containing the pressure generated through the pumping process safely.

1.2.12 - Initial Problems with UT Data Collection

The repeatability of ultrasonic measurement was questionable due to errors in the positioning of the probe.

It was almost impossible for the NDT technician to ensure that the probe was positioned in the exact same area, meaning that the data gathered was not easily comparable to the initial readings.

To rectify such errors, thickness measurement locations markers installed on all units that underwent such inspection, as it would ensure the following inspections provided directly comparable thickness data.

1.2.13 - Figure 13 – Thickness Measurement Location, (TML), markers



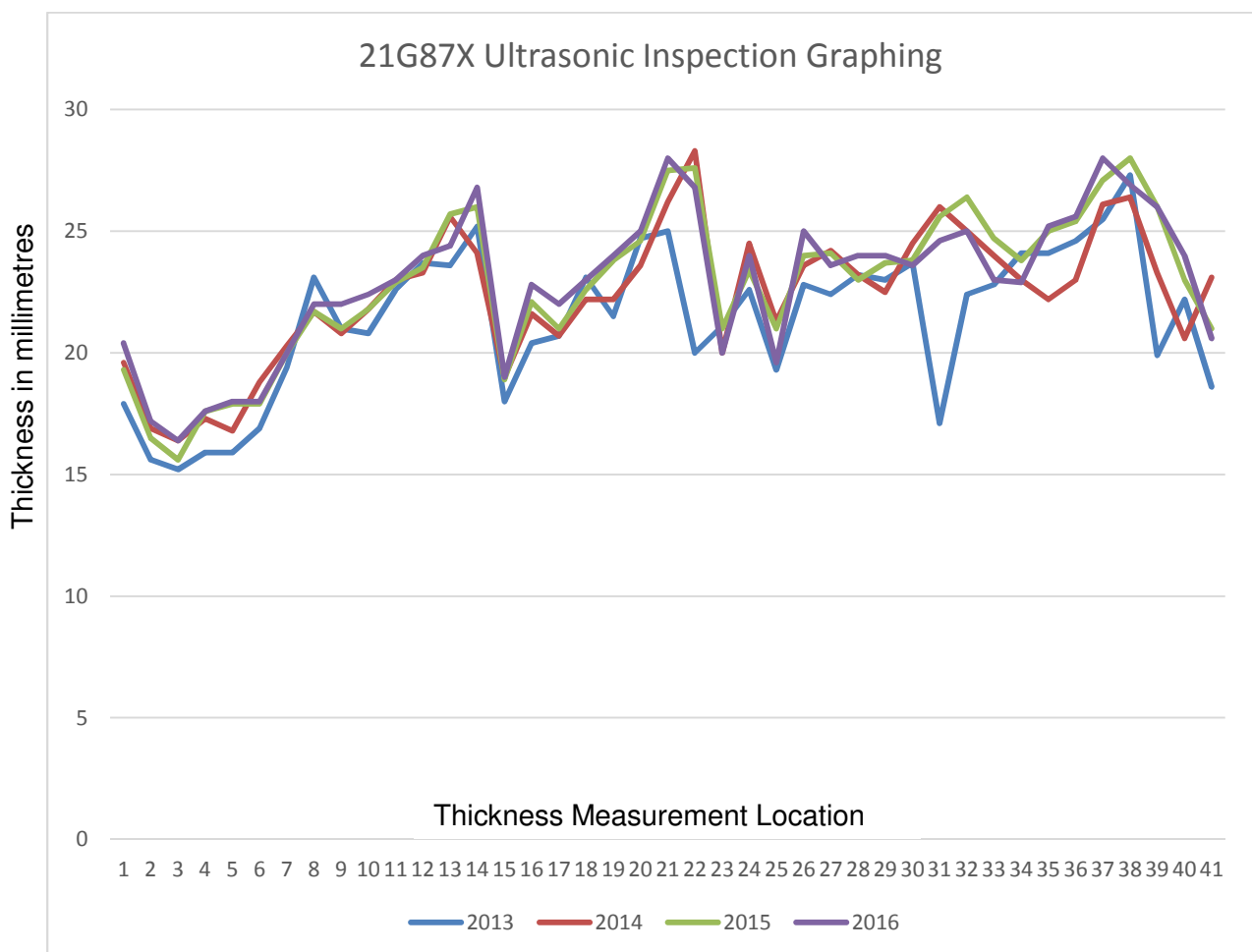
As the thickness measurements were now reliably gathered, it meant that the data could be graphed, (see figure 14). These inspections highlighted any obviously differing measurement points and hence meant they could be further investigated, or discounted if obviously spurious.

A range of reasons for erroneous results were highlighted such as change of probe, differing or new staff and surface cleanliness, and it was found that discrepancies of some millimetres were in fact not uncommon with such measurement equipment.

Due to these variations, it was necessary to populate a large data base allowing easy identification of any obviously spurious results.

1.2.14 - Figure 14 – Graph 1 - Pump Set UT Graphing

Figure 13 was generated from four years of annual UT inspection on the unit elaborated on within the intrusive data gathering section.



As can be seen in figure 14, although there appear to be discrepancies as high as five or six millimetres in some cases, there are no thickness measurement locations that show a general downward thickness trend.

As graphical representation offered such easily comparable data, it was deemed that UT inspections were in fact very useful on pump casings and associated equipment.

A typical clear lack of downward trend in thickness meant that the conclusion could be drawn on hydrocarbon pump sets at the site, in that, the usage conditions seen since becoming a storage facility meant that casing thickness loss was not a significant failure mode in regard to its potential to lead to uncontrolled hydrocarbon release.

The frequency of inspections was therefore extended to five yearly as opposed to annual, with the intention of further extending this interval if future inspections show little change in these measurements.

1.3.0 - Limitations of 90° Probe Ultrasonic Thickness Measurement Inspections

Although ultrasonic inspections highlighted any material flaws and gave an indication of any thinned areas, there were limitations to this data collection method.

A material flaw was highlighted in a pump casing, the nominal thickness of the volute casing being twenty millimetres, with one area measured at six point six millimetres.

1.3.1 – Figure 15 – Volute Casing Defect Location



Point measured at 6.6mm thickness

1.3.2 – Casing Irregularity Investigations

To further investigate this anomaly, an endoscope was used to view the casing internally as a casing defect of this size if internal, was expected to be obvious, although this proved not to be the case with the area in question looking similar to that of the casing around it.

As the thickness loss was proven not to be internal, if the indicated difference in thickness was correct, the irregularity should have been clearly visible externally, but again this was not the case with only a small external undulation of less than two millimetres in depth.

Following the inspections, a third-party consultancy firm, IDEAS, were contacted and the following details provided of the findings thus far.

- A UT inspection had been performed
- An anomaly had been identified within the wall of the volute
- There were no large variations internally or externally visible to the naked eye

Extracts from this consultation can be found as Appendix 1.

Following the consultation, it was decided that a thickness loss such as was depicted in the ultrasonic inspection was most likely erroneous, with (IDEAS, 2013) stating “*laminations and other defects you can get with castings can throw these readings*”.

Based in part on the above assessment, it was decided that the apparently thinned area should be investigated prior to the unit going back into service via further non-destructive testing.

It was therefore decided that the following NDT methods would be implemented to prove or disprove the 6.6mm reading in this area:

- An X-ray be performed to determine whether there was a void within the casing wall
- A multi directional UT inspection be performed known as Shear Wave be carried out to identify the size and shape of the defect, should it be a lamination within the volute wall

1.3.3 - X-Ray of Casing Wall

Following an X-ray of the area in question, a report was provided by IRISNDT, a local specialist company, which highlighted that the area in question was of similar thickness to the rest of the volute casing. (IRISNDT, 2013) “The area in question shows a similar thickness to the adjacent area this can be seen due to density of radiograph being similar, the area adjacent is approx.17-20mm thickness”.

1.3.4 - Fig 16 - X-Ray Image of Casing Wall

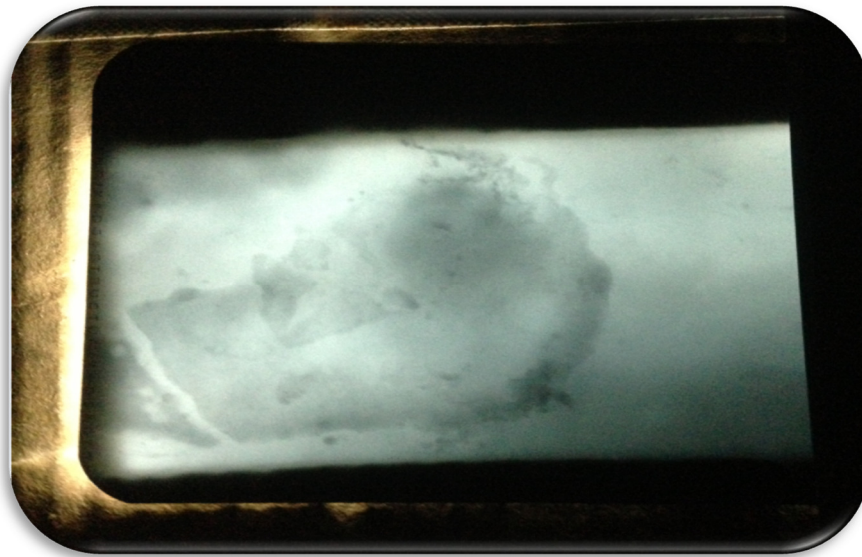
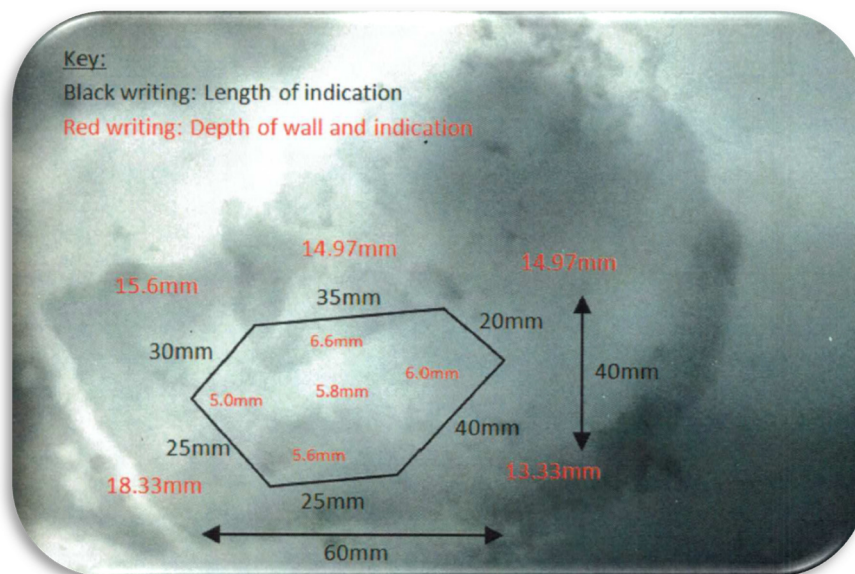


Figure 16 provided evidence that the area in question was in fact of similar thickness to the rest of the pump casing, and therefore the reason for the results of the ultrasonic inspection should be further investigated.

1.3.5 – Shear Wave UT Inspection of Casing

Shear wave ultrasonic inspection would establish the exact depth, shape and size of the material defect, and was therefore performed. Following this, interpretation of figure 17 was provided.

1.3.6 - Fig 17 – Shear Wave Inspection Interpretation of X-ray



As can be seen in figure 17, only a small area was affected, extract of report can be found as Appendix 2.

1.3.7 – Analysis of X-ray & Shear Wave NDT

It became apparent that whilst there did appear to be a material defect, it was most likely a lamination as opposed to a loss in thickness or void within the casing wall.

Anomalies were not uncommon within pump casings, (IDEAS, 2013), and the most likely explanation was a weld repair required to fill a slag hole or other defect during the manufacture process.

It was deemed that carrying out a repair on this area was not required, even if a lamination such as this proved to be indicative of poor fusion of a weld at manufacture phase. (IDEAS, 2013) “this type of defect does not have any significant effect on the strength required for pressure containment (you can liken this to a laminated sheet of plywood as opposed to an equivalent size piece of timber)”.

It would not have been foreseen at manufacture stage that a weld repair, as it appears to be, would cause the unit to have to be removed for non-destructive testing to prove its integrity.

By performing such inspections, it should be possible to prove the integrity of such pumps for many years to come.

The casing was subject to a pressure test to further prove its integrity and allowed to return to service.

1.3.8 – Cost saving to The Company

This project had significant cost benefit to the company as manufacture of a replacement casing, due to its age, would have had to be a one-off production priced at £44,402.

Breakdown of cost saving as follows:

- Initial UT inspection and provision of report: £240
- X-ray inspection and provision of report: £100
- Shear wave UT inspection and provision of report: £100

The above cost savings could be quantified as approximately £43,962.

If it had not been possible to prove the initial ultrasonic inspection findings as erroneous, and through this the integrity of the casing, a new casing or complete unit would have had to have been purchased at large monetary cost to the company.

Casing quotation can be found as Appendix 3.

1.3.9 – Thermography

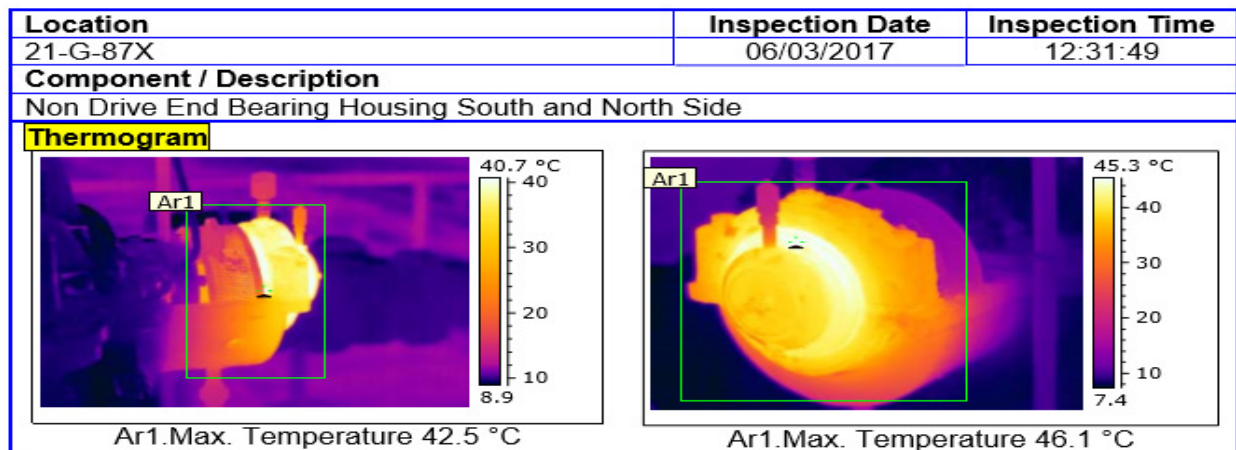
A further non-intrusive data collection method implemented at the site is thermography. This involves use thermal imaging cameras to give an accurate representation of a machines health based on ‘hot spots’ linked to issues such as misalignment, bearing degradation or poor lubrication of rotating components. (Avio, 2017) “equipment or method, which detects infrared energy emitted from object... and displays image of temperature distribution”.

One case in particular at the site was that of pump set 21G87AX, the non-drive end of this queried as appearing to be running hot through a look listen, feel assessment during the pumps use.

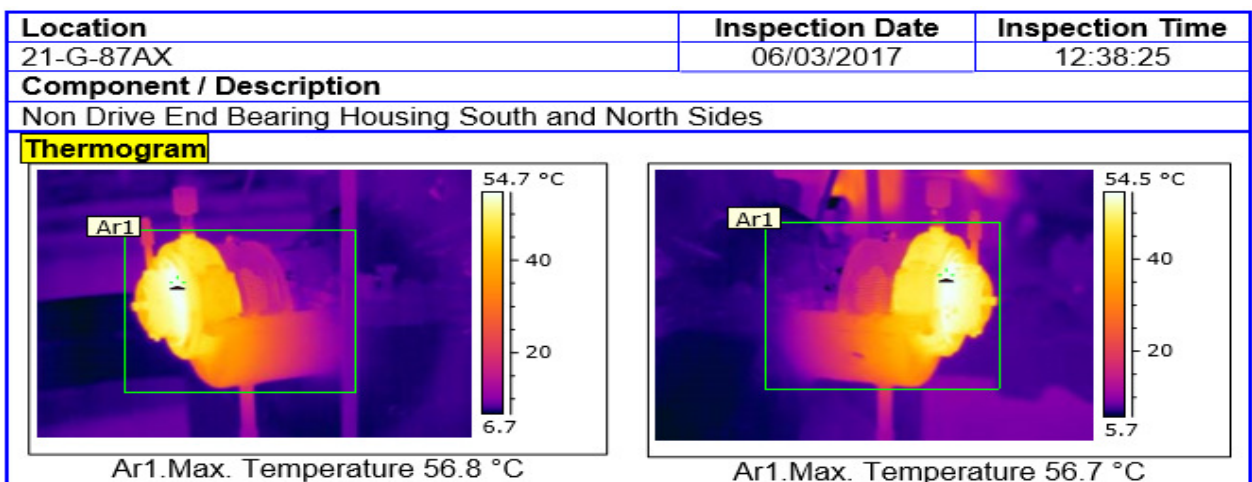
An infra-red temperature probe was then used to verify this which highlighted that this bearing did indeed appear to be running hotter than the neighbouring unit 21G87X.

The decision was taken to have a thermographic survey carried out to ascertain the exact temperature difference of these bearing and deem whether any corrective action was needed.

1.3.10 – Figure 18 – 21G87X Non-Drive End Thermographic Imaging



1.3.11 – Figure 19 – 21G87AX Non-Drive End Thermographic Imaging



The thermography showed that although there was a small difference in temperature in comparison to the neighbouring unit, approximately 10°C. The difference was attributed to the unit not having yet undergone refurbishment and hence it was possible that the grease may have lost some of its lubricating properties.

Recent vibration data listed the machine as healthy, additionally (Whitcher, 2017) stated “No items of concern were identified...the bearing housing temperature is not excessively high”.

In light of the thermographic survey and recent vibration analysis, the difference in bearing temperature was not deemed a cause for concern, hence the unit would stay in service until the time it was refurbished.

Periodic condition monitoring allowed tracking of any further degradation. See Appendix 4 for thermography report extract.

2.0.0 - Sporadic Usage Related Findings

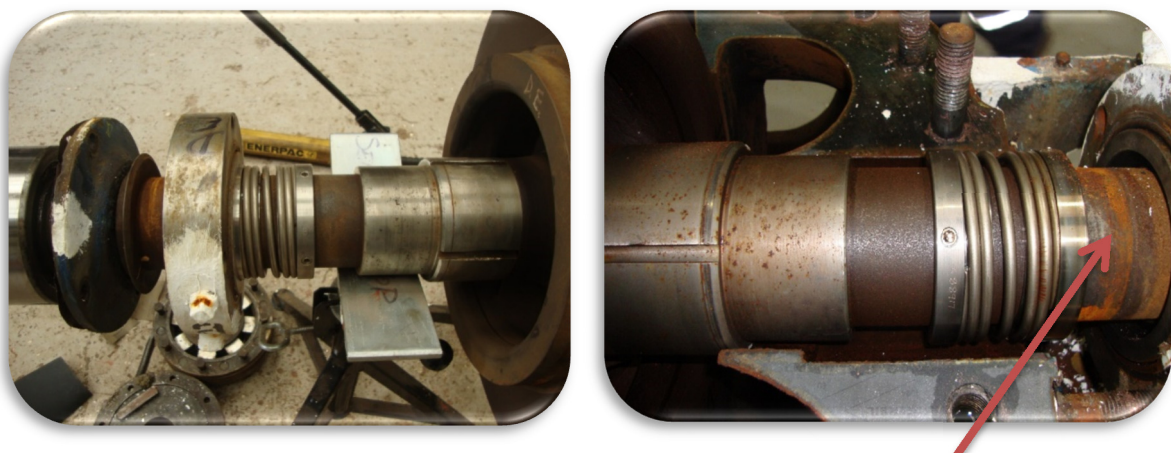
The change from running refinery to storage facility has meant that such equipment can sometimes lay dormant for extended periods. Both pumps, and agitators, have shown evidence of inactivity related failure modes becoming effective, that may not have been envisaged by the manufacturers.

2.1.1 – Pump Modification for Sporadic Usage

This section of this report will detail the failure modes that have become effective at the site in the earlier stages of transition from refinery to storage facility, and the corrective steps that have since been implemented to aim to minimise such occurrences.

During an intrusive data collection inspection on a centre hung pump, it was found that a section of shaft that the seal runs on had developed surface corrosion, causing interference on the rotary seal ring internal diameter.

2.1.2 - Figure 20 – Seal Running Area



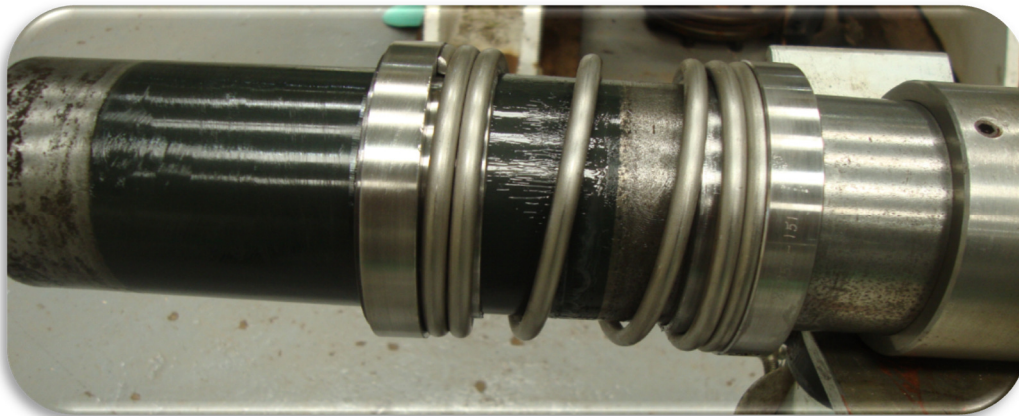
Closer view of corroded shaft

This interference had prevented the rotary seal ring, (RSR), from moving up the shaft to meet the stationary seal ring, (SSR), as the faces wore over time which was allowing seal seepage.

During normal usage of pumps, a regular flow of product would not allow such corrosion to develop. As the usage conditions at the site meant long instances where equipment lay dormant, a build up of surface corrosion in figure 20 was unavoidable.

A non-corroding Chrome-Oxide coating was applied in the area that the mechanical seal ran, meaning that corrosion would not occur, lessening the chance of future instances of this failure mode becoming effective.

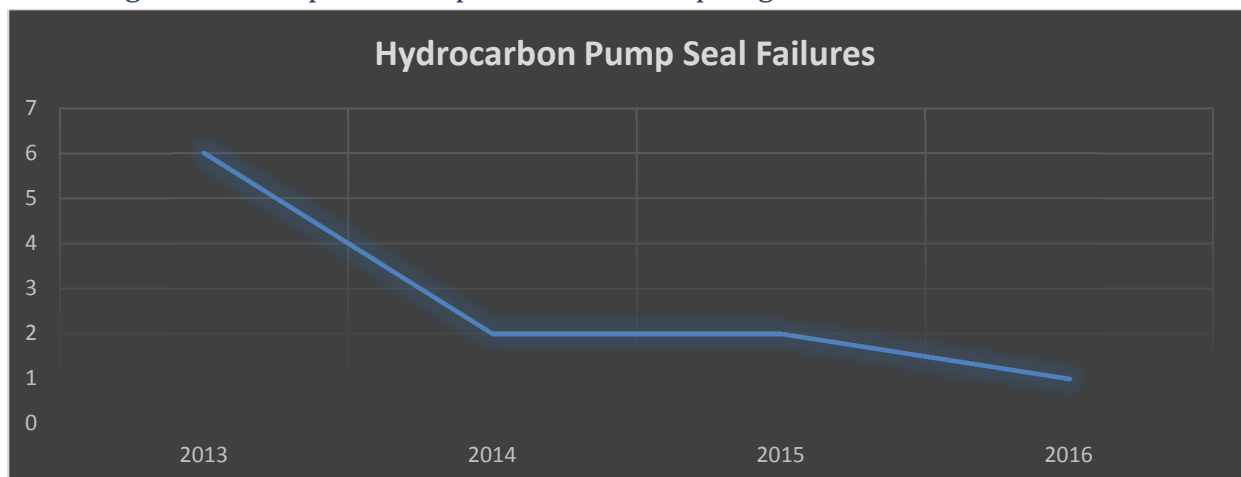
2.1.4 - Figure 21 – Chrome Oxide Coated Shaft



Evidence of non-recurrence of seal failure on this unit since these changes can be seen within seal failure spreadsheet Appendix 5, (21G87X row).

Reductions in seal failures have been graphed at the site since 2013 and show a clear downward trend, see figure 22.

2.1.5 - Figure 22 – Graph 2 - Pump Seal Failure Graphing

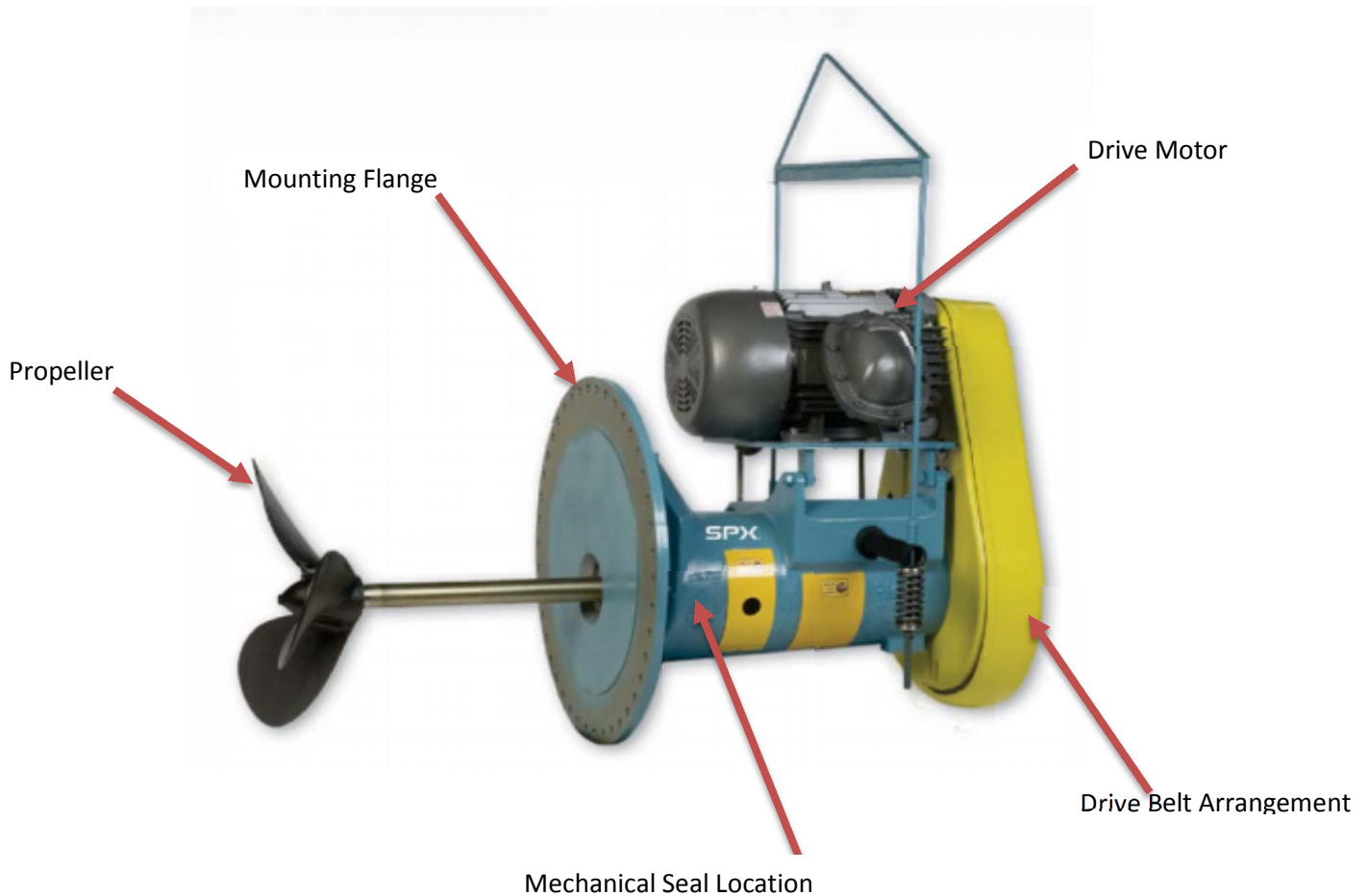


2.1.6 - Tank Agitator Modification for Sporadic Usage & Multi Product Use

Part of the business as a storage facility is to bring in different batches of product and blend them to achieve the grade required by the customer. This blending is achieved by importing two or more cargos of differing grade into the same tank and mixing them via means of a tank agitator, or mixer, essentially a large shaft driven impellor mounted on the tank wall.

2.1.7 - Figure 23 – Belt Driven Tank Agitator GA

Plenty Mixer: (ctctcdn)



As with pumps, the tank agitators were found to have sporadic usage and multi product related issues.

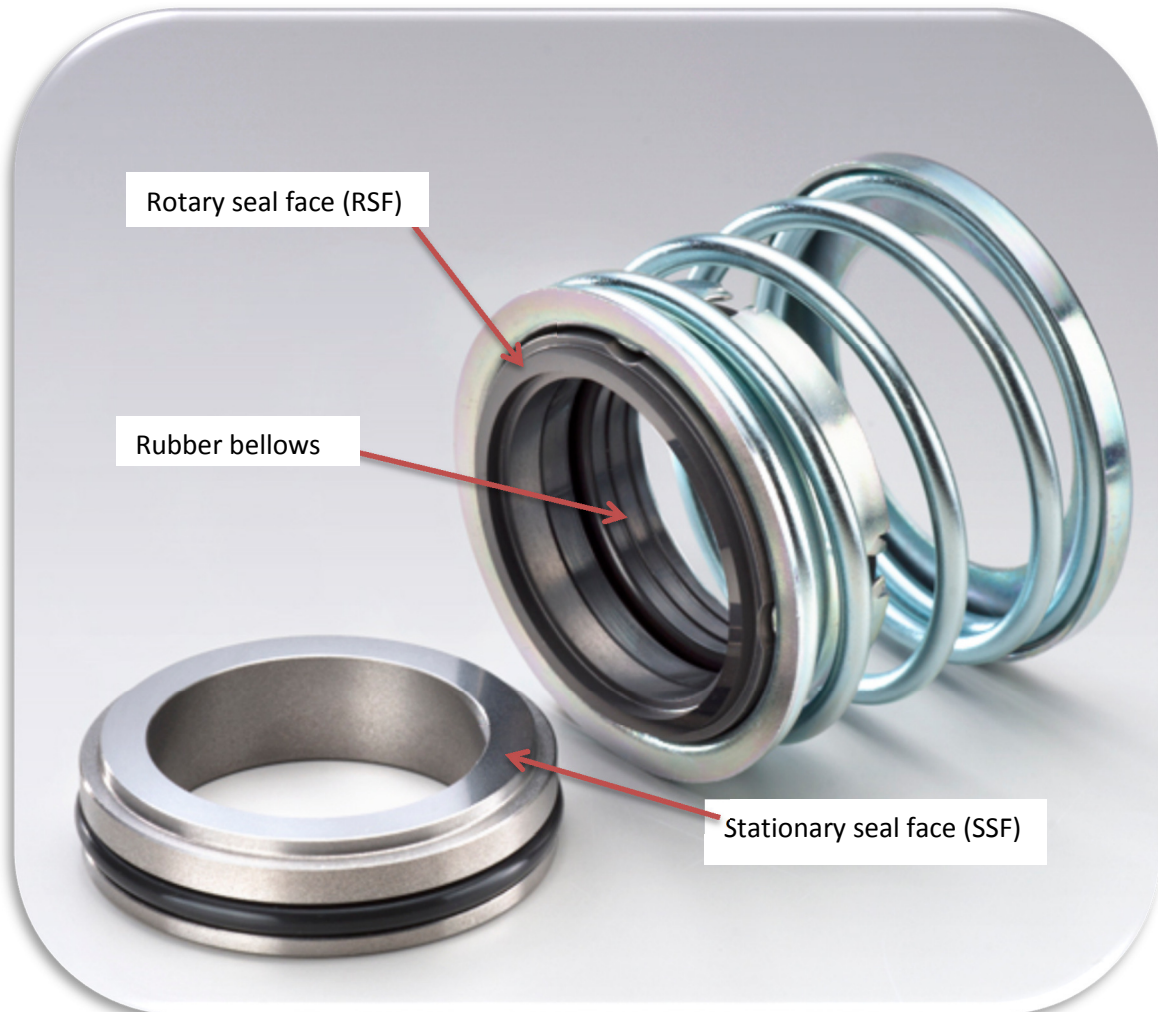
The most problematic aspect was found to be the 'Mitchell Craig' manufactured units sealing arrangements inability to deal with multi product use, and periods of dormancy.

2.1.8 – Agitator Mechanical Seal General Arrangement

Mechanical seals are comprised of a number of components; this section concentrates on the following elements: Stationary seal face (SSF), Rotary seal face (RSF) and a rubber bellows which centralises and provides drive to the RSF.

A general arrangement of a mechanical seal, similar to that in use on Mitchell Craig agitators, can be seen in Figure 24.

2.1.9 - Figure 24 – Mechanical Seal General Arrangement



2.1.10 - Rubber Component Incompatibility for Multi Product Service

The SSF is held in place with an external O-ring within a seal housing, the RSF centralised on the shaft with a rubber 'bellows' providing friction drive from the shaft. Also integral to a mechanical seal is the external spring which compresses the bellows and pushes the RSF toward the SSF as they wear.

As a storage facility, many of the tanks were now in multi-product hydrocarbon use, meaning the seal components were now used with products they were not originally designed to come into contact with, for instance Gasoil as opposed to Gasoline.

Due to the differing product service, some bellows were starting to degrade and misshape, causing the sealing faces to misalign from each other, allowing moderate leakage.

2.1.11 – Seal Face Material Failure Due to Inactivity

The original mechanical seal components in use on these mixers comprised of a cast iron SSF, and Carbon Graphite compound RSF.

During periods of inactivity, the SSF developed surface corrosion causing product leakage upon run up of the unit. Although not catastrophic, such seal failures were common during this transition period.

An initial SSF material change to Silicon Carbide was originally considered a success, as small seal failures became less frequent at the site, but quite catastrophic seal failures were now occurring after further periods of inactivity.

Upon consultation with the seal manufacturers used at the time, it was suggested that ‘wringing’ may be the cause of these failures. Wringing is essentially sticking together of the faces, the same principle as engineering slips that can stick together because of their high surface finish, when all air or fluid is pushed from between them. (Kumar, 2013) elaborates “Due to adhesion properties of slip gauges, they will stick together. This is because of a very high degree of surface finish of the measuring faces.”

The wringing was attributed to the higher surface finish of the Silicon Carbide SSF, combined with the high surface finish and relatively low shear strength of the Carbon Graphite material, used for the RSF at this time.

Once the sealing faces had wrung together, instances of serious seal failures were being seen upon start-up of the equipment, with a substantially large seal leak immediately developing, found to be due to fracturing or tearing of the Carbon Graphite RSF.

2.1.12 - Changes to Rubber Components – Post PDS & FMEA

In light of the worsening of the seal leakage following this poorly implemented change, a FMEA and product design specification were performed prior to any further modification, these can be found as Appendices 6 & 7 respectively.

As the changes in product service could not be avoided, a replacement compound, Viton, was chosen for the rubber seal components as opposed to the existing Nitrile material.

Although there is a chance of Viton distortion in some product services, it is generally considered a much more robust material, more capable of dealing with a range of products.

(ENARUBBER, 2015) “Viton has excellent resistance to high temperatures (up to 204 degrees Celsius), ozone, oxygen, mineral oils, synthetic hydraulic fluids, fuels, aromatics

and many organic solvents and chemicals”. This meant it was considered a much better choice than the existing elastomer, Nitrile, in this instance.

No failures due to degradation of bellows material have been documented since the use of Viton instead of Nitrile, evidence of this found within Appendix 8 (tank mixer seal failures).

2.1.13 - Changes to Seal Face Materials

Due to the catastrophic seal failures attributed to wringing, the use of Silicon Carbide as a RSF material also was investigated. Silicon Carbide is not expected to corrode or degrade in the product service seen at Sem Logistics. (AZO Materials, 2001): “the high hardness, corrosion resistance and stiffness lead to a wide range of applications where wear and corrosion resistance are primary performance requirements”

It was decided both faces were now to be made from Silicon Carbide of differing hardness, as this allows necessary wear to achieve efficient sealing. Both faces being the same grade may lead to scoring rather than sympathetic wear, a cause of seal seepage.

Silicon Carbide even in its softer form as the wearing RSF, has far higher fracture or tear resistance than Carbon Graphite; see: (AZO Materials, 2000) which gives the shear modulus of Carbon Graphite between 1.7 – 11.5 GPa, whereas (AZO Materials, 2001) gives the shear modulus of Silicon Carbide between 33.93 – 35.6 GPa, many times above that of Carbon Graphite. Hence there was less chance of catastrophic failure upon start-up even if wringing had occurred, due to its much higher tear resistance or shear strength.

These figures can be seen in the following tables.

2.1.14 Figure 25 – Carbon Graphite Properties (AZO Materials, 2000):

Property	Minimum Value (S.I.)	Maximum Value (S.I.)	Units (S.I.)	Minimum Value (Imp.)	Maximum Value (Imp.)	Units (Imp.)
Shear Modulus	1.7	11.5	GPa	0.246564	1.66793	10 ⁶ psi

2.1.15 - Figure 26 – Silicon Carbide Properties (AZO Materials, 2001):

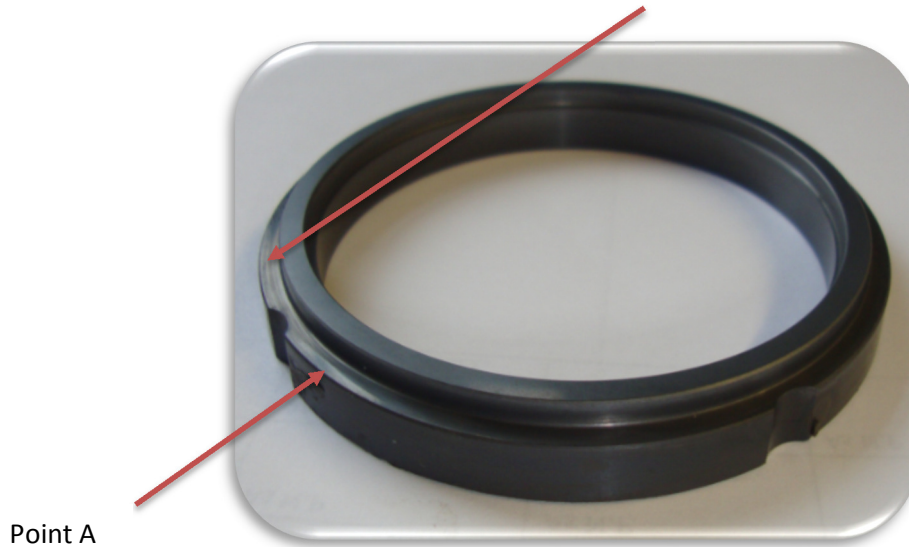
Property	Minimum Value (S.I.)	Maximum Value (S.I.)	Units (S.I.)	Minimum Value (Imp.)	Maximum Value (Imp.)	Units (Imp.)
Shear Modulus	33.93	35.6	GPa	4.92113	5.16334	10 ⁶ psi

2.1.16 - Change in Seal Face Design – Stepped RSF

To help counteract wringing, the RSF is now stepped, figure 27.

2.1.17 – Figure 27 - Stepped RSR

Force of header pressure of tank now acts on this face



The stepped area of the RSF allows a certain amount of what is known as hydraulic balance within the assembly, the small void, (Point A in figure 27), between the sealing faces causes the fluid to push against the RSF, effectively reducing the force pushing it toward the SSF.

This principle is elaborated on by (Pope, 1997), where it is stated; “This reduction now exposes more of the front side of the rotating seal face to the seal chamber pressure. Because pressure acts in all directions, this increased exposure opposes or negates a large portion of the pressure and effectively reduces the closing force acting on the seal face.”

The magnitude of the benefit the stepped RSR would offer was investigated prior to its implementation, as implementation without full consideration in the past had led to the worsening of the issue.

2.1.18 - Pressure within sealing system calculations

A calculation was carried out to establish the force acting on the newly exposed area due to the product head, as follows:

All following calculations are accurate to 2 decimal places.

Maximum tank fill level: 18m

Average specific gravity of products: 0.8kg/m³

1m of water head gives a pressure of 9807N/m²

Pressure at 18m of product head = $9807 \times 18\text{m} \times 0.8 = \underline{141.2\text{kN/m}^2}$

Force acting against rear of RSF due to product head: (Force = Pressure x Area)

$$\text{Area} = \pi(82\text{mm}/2)^2 - \pi(70\text{mm}/2)^2 = 1432.57\text{mm}^2 \text{ or } 1432.57 \times 10^{-6}\text{m}^2$$

$$\text{Therefore } 141.2 \times 10^3 \times 1432.57 \times 10^{-6} = \underline{\underline{202.28\text{N}}}$$

Force acting against front (stepped area) of RSF due to product head:

$$\text{Area} = \pi(82\text{mm}/2)^2 - \pi(76\text{mm}/2)^2 = 744.56\text{mm}^2 \text{ or } 744.56 \times 10^{-6}\text{m}^2$$

$$\text{Therefore } 141.2 \times 10^3 \times 744.56 \times 10^{-6} = \underline{\underline{105.13\text{N force}}}$$

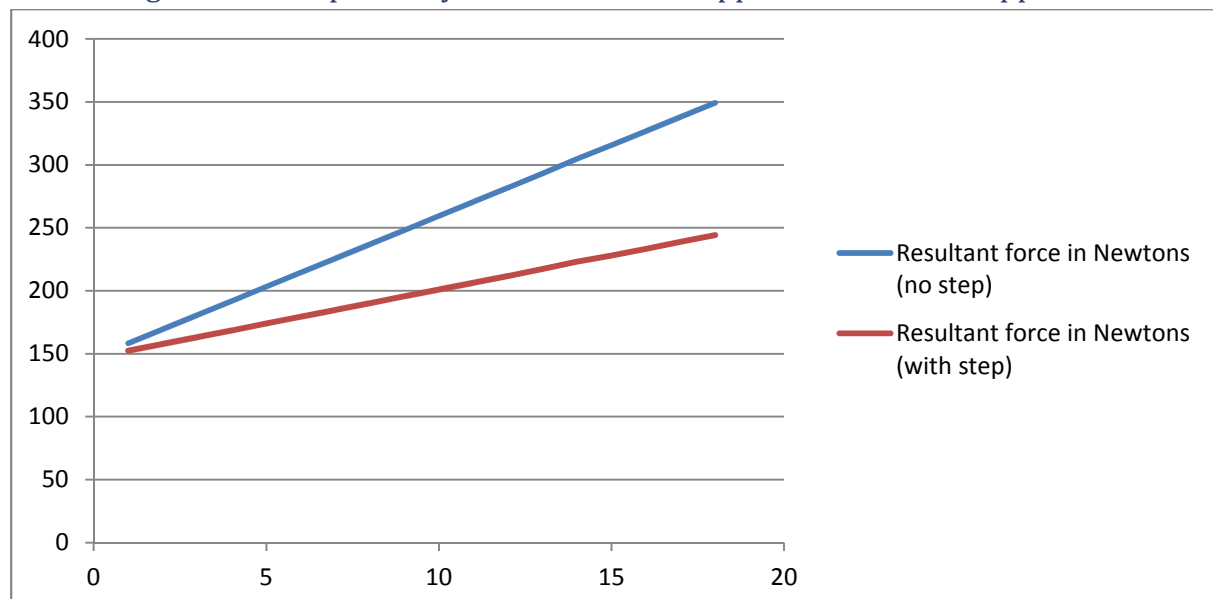
Complete Seal Assembly Calculations:

- Spring force: 147N
- Force pushing RSF towards SSF due to product head = 202.28N
- Force pushing RSF back due to stepped face = 105.13N
- Resultant force acting on seal arrangement = $(202.28 + 147) - 105.13 = \underline{\underline{244.15\text{N}}}$
- Repeating the above calculations without the hydraulic balance offered by a stepped sealing face equates to = **349.28N** (43% higher than with a stepped RSF)
- A non-hydraulically balanced seal is subject to higher force, increasing at a much higher direct proportion due to product level than a balanced seal. A graphical representation of this reduction in force can be seen in figure 28.

Sealing Assembly Observations:

The closing force acting within the sealing assembly without the benefit of being hydraulically balanced results in a 43% increase, meaning a far higher chance of seal wringing.

2.1.19 - Figure 28 – Graph 3 – Hydraulic Balance Stepped RSF vs Non-Stepped



2.1.20 - Conclusion of hydraulic balance calculations

The reduction in force within the sealing assembly by using hydraulic balance may seem like an obvious choice in regard to seal design, as it reduces chance of wringing, although other considerations should be fully evaluated before implementation:

The reduction in sealing face contact area due to stepping the RSF incurs greater pressure within the sealing face materials. Continued use of Carbon Graphite as a stepped RSF without consideration of this has potential to cause failure or excessive wear, further justifying use of Silicon Carbide for both faces, its higher compressive strength and endurance limit properties make it more suitable.

2.1.21 - Figure 29 – Silicon Carbide Compressive Strength & Wear Properties

Carbon Graphite (AZO Materials, 2000):

Property	Minimum Value (S.I.)	Maximum Value (S.I.)	Units (S.I.)	Minimum Value (Imp.)	Maximum Value (Imp.)	Units (Imp.)
Compressive Strength	31	345	MPa	4.49617	50.038	ksi
Endurance Limit	15.47	18.05	MPa	2.24373	2.61793	ksi

2.1.22 - Figure 30 – Carbon Graphite Compressive Strength & Wear Properties

Silicon Carbide (AZO Materials, 2001):

Compressive Strength	130	1395	MPa	18.8549	202.328	ksi
Endurance Limit	175	705	MPa	25.3816	102.252	ksi

Some literature suggests a stepped RSF may cause instability during use, which has potential to cause premature seal wear. (Jr., 1984) states in regard to a stepped face; “an unbalanced seal is always stable but balanced seals may be unstable at certain pressures.”

Increased chance of premature wear due to use of a stepped RSF, was considered a minor compromise compared to the far lower chance of catastrophic failure due to wringing.

The magnitude of wringing related hydrocarbon containment loss was far higher than the small chance of leakage due to premature sealing face wear, counteracted by the use of the harder wearing Silicon Carbide material.

2.1.21 – Evaluation of Mechanical Seal Changes on Agitators

The result of the changes to seal face material, hydraulic balance design and upgrade of rubber bellows, has been that the failures seen due to their inability to deal with the usage conditions now seen at the site have been eradicated.

2.1.22 – Figure 31 – Agitator Seal Failure Upgrade & Failure Logging

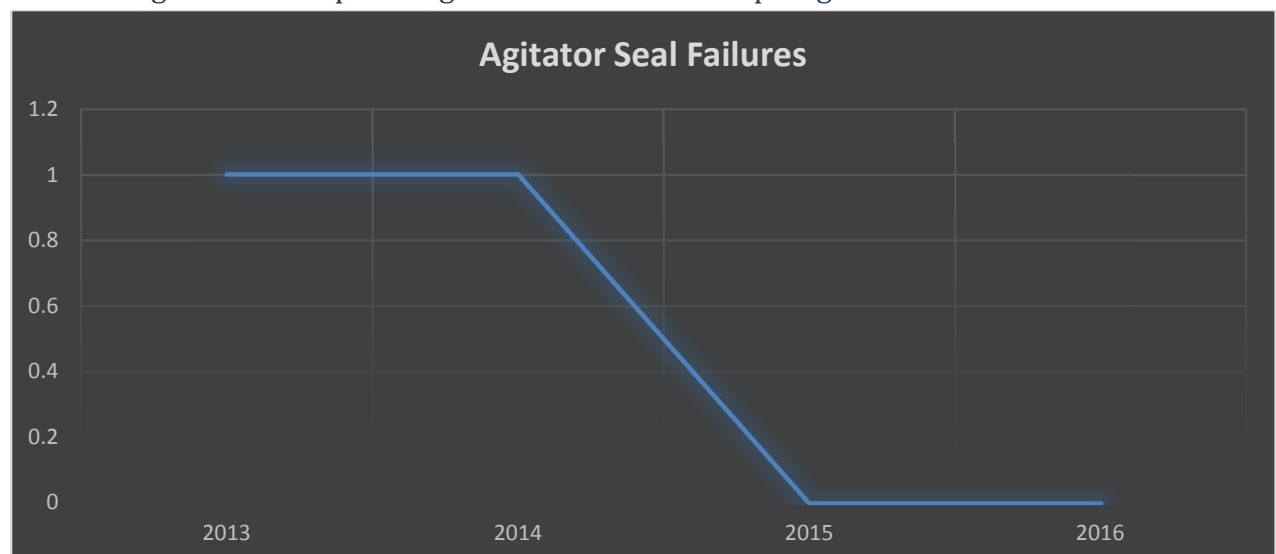
Tank Mixer Seal Failure	2013- Jan-June	2013 Jul-Dec	2014- Jan-June	2014 Jul-Dec	2015- Jan-June	2015 Jul-Dec	2016- Jan-June	2016 Jul-Dec
West Tankage								
Tank 1 A	0	0	0	0	0	0	0	0
Tank 1 B	0	0	0	0	0	0	0	0
Tank 2 A	0	0	0	0	0	0	0	0
Tank 2 B	0	0	0	0	0	0	0	0
Tank 3 B	0	0	0	0	0	0	0	0
Tank 3 C	0	0	0	0	0	0	0	0
Tank 4 A	0	0	0	0	0	0	0	0
Tank 4 B	0	0	0	0	0	0	0	0
Tank 5 A	0	0	0	0	0	0	0	0
Tank 5 B	0	0	0	0	0	0	0	0
Tank 6 A	0	0	0	0	0	0	0	0
Tank 6 B	0	0	0	0	0	0	0	0
Tank 7 A	0	0	0	0	0	0	0	0
Tank 7 B	0	0	0	0	0	0	0	0
Tank 8 A	0	0	0	0	0	0	0	0
Tank 8 C	0	0	0	0	0	0	0	0
Tank 9 B	0	0	0	0	0	0	0	0
Tank 9 C	0	0	0	0	0	0	0	0

Key		
Least preferred seal arrangement or seal arrangement unknown		Michell Craig with old seal
Low risk seal arrangement		Gear driven plenty
Medium risk seal arrangement		Michell Craig with preferred seal arrangement
Preferred seal arrangement		New mixers belt driven

As part of the ongoing approach to bettering the sites equipment failure rates, seal failures are now logged, see extract as figure 31, in order to predict when they may next occur. This has highlighted that there has not been one recurrence of the agitator failure modes documented.

As with the pump seal failure logging performed since 2013, the agitator seal failure graphing also shows a clear downward trend, figure 32.

2.1.23 – Figure 32 – Graph 4 - Agitator Seal Failure Graphing



3.0.0 – Upgrading of Equipment to Modern Standards

Another requisite in demonstrating a proactive approach to ageing plant condition monitoring and maintenance is to prove a constantly improving methodology is taken.

3.1.1 - Double Mechanical Seal Retrofit Summary

When replacement of equipment is not feasible whether that be to operational requirements, cost, or other factors the upgrade of existing plant may be considered. The pump that underwent casing irregularity NDT and investigation was an example of such a case.

The unit was one of two pumps that, due to pumping gasoline only, was deemed to be the highest risk of fire hazard should a seal leak occur.

A cost benefit analysis was performed to ascertain whether modernisation of these pumps was feasible, but the cost of replacements was deemed prohibitive.

The decision was taken to upgrade the pump to modern day standards by retrofit of an upgraded mechanical sealing arrangement.

A double mechanical system was chosen, which comprised of the following:

- A primary sealing arrangement that houses the pressure generated from the pumping process
- A void which contains a pressurised barrier fluid
- A secondary seal that contains the pressurised barrier fluid

This arrangement offers benefits in regard to its risk as even if a primary seal failure occurs, rather than the process fluid venting to atmosphere it is contained within the barrier fluid.

A primary seal leak will be apparent through either discolouration or an elevation in the barrier fluid level.

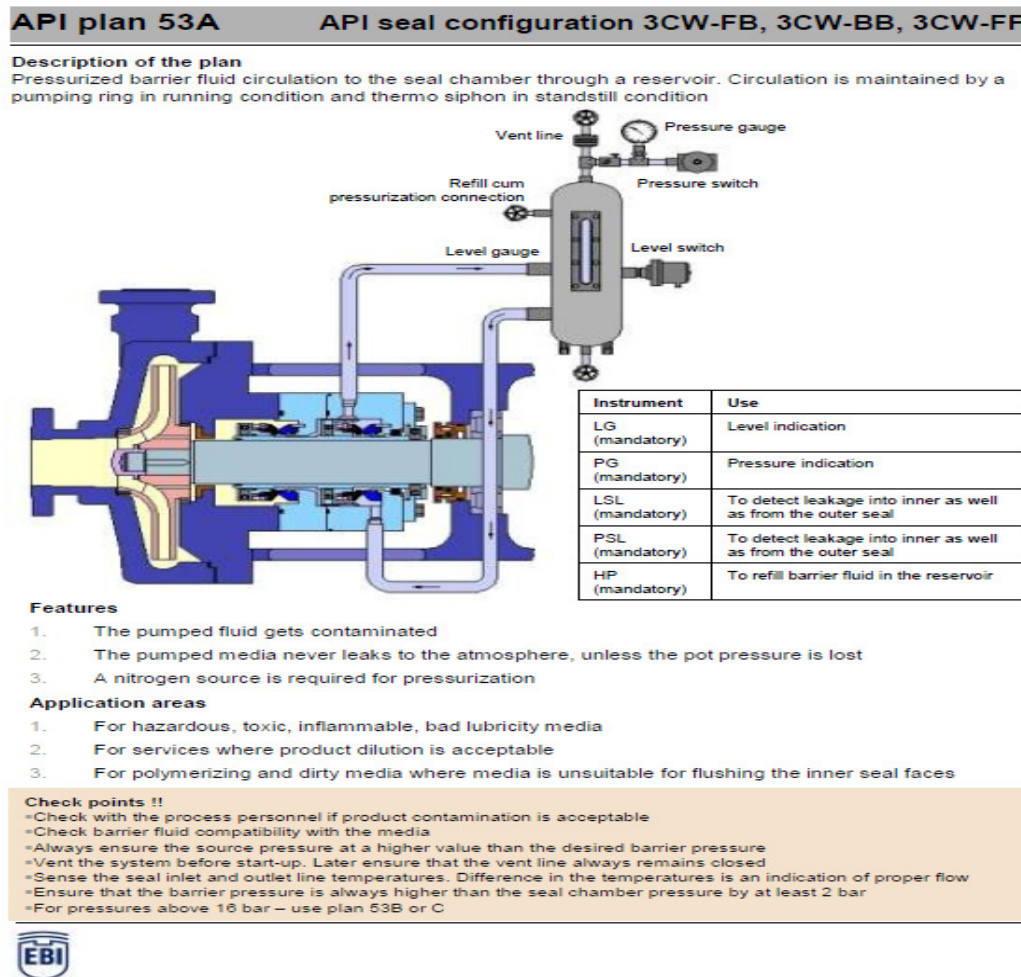
This containment means lower risk of environmental pollution, lesser chance of damage to plant or injury to personnel, and hence reduced risk to the business.

As a primary seal failure would not lead to a release of product to atmosphere, it is also considered beneficial to the site in bettering uncontrolled hydrocarbon release rates, as a failure would still technically be controlled.

Following discussions with third party engineering consultancy firm, IDEAS, the decision was taken to fit an 'API 53A' design sealing arrangement, as stipulated within specification "1695-REPT-SEM-53-0082" - relevant sections of which can be found as Appendix 9.

The '53A' design was recommended as the usage conditions met two of the three application guidelines within Figure 33; (1) For hazardous, toxic, inflammable, bad lubricity media, (2) For services where product dilution is acceptable.

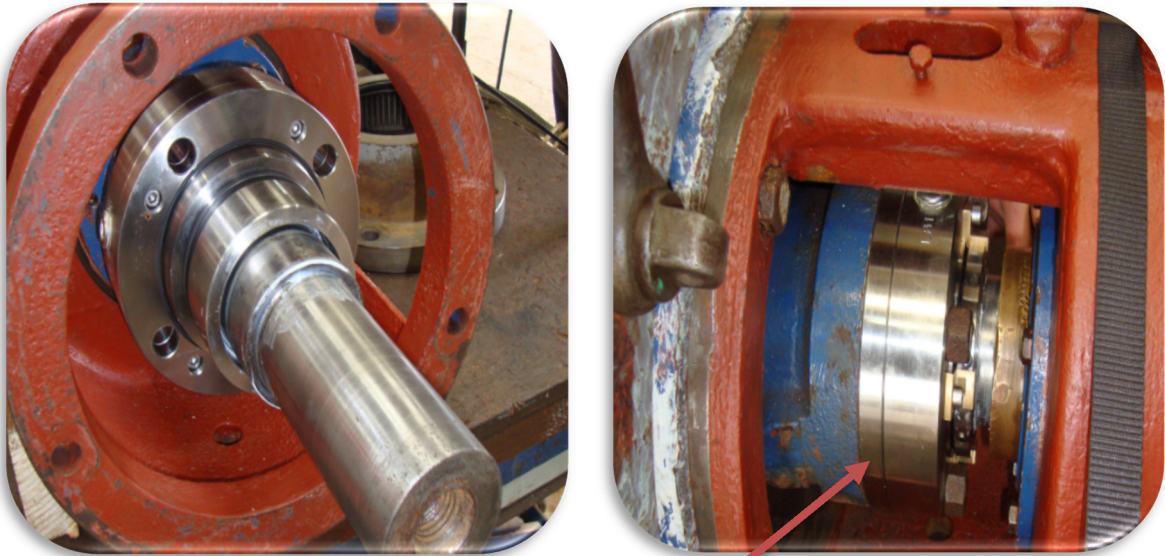
3.1.2 – Figure 33 – 53A Design Mechanical Sealing Arrangement



Prior to performing of the retrofit of this system a Hazop, or Hazard and Operability analysis, was carried out by a third party, IPDS. The intention of the Hazop was to establish whether there was a need to carry out this alteration, and also assess whether in doing so any further problems could occur.

It was deemed that double mechanical seal fitment on the unit would reduce the chance of incident when compared to the single sealing arrangement currently in use, and was hence installed as depicted below. An extract of the IPDS Hazop can be found as Appendix 10.

3.1.3 – Figure 34 – Fitment of Upgraded Sealing Arrangement in Progress



Located in place of single mechanical arrangement.

3.1.4 – Figure 35 – Pump Relocated in Situ



3.1.5 - Initial Test Run Findings

Following the refurbishment and fitment of the double mechanical sealing arrangement, the unit was installed and test run.

Upon initial 1.25 hour run up of the system, the following was found:

- The temperature of the barrier fluid steadily climbed from outdoor ambient, (February 2016 so around 5 degrees Celsius), to 70+ degrees Celsius.
- The barrier fluid level rose by around 25mm on the site glass, this was confirmed as thermal growth as the level returned to prior following cooling of the system.
- The pressure of the barrier fluid steadily climbed from 12.4 bar 15.6 bar, appearing to be caused by the thermal growth of the barrier fluid.

Although an elevation of these is expected the system is meant to reach equilibrium, as this did not appear to be the case these concerns were put to the seal supplier, an extract from this correspondence can be found as Appendix 13.

It was found that the reason for the elevation in the levels described was most likely due to an unrealistic output pumping pressure of 10.4 bar, which was the output pressure that the seal specification was designed around.

During the running of the unit it was found that the outlet pressure of the pump was closer to 5.5 bar meaning the unnecessary difference in barrier fluid pressure was causing additional heat in the system.

Differences in discharge pressure can vary due to discharge rate required, head of product, and amount the discharge valve is open, hence the following barrier fluid pressure was ranges were decided on though consultation with the seal supplier.

- If the discharge pressure is 85psi, please set the barrier fluid to 66psi
- If the discharge pressure is 90psi, please the barrier fluid pressure to 67-68psi
- If the discharge pressure is 95psi, please set the barrier fluid pressure to 68-69psi
- If the discharge pressure is 100psi, please set the barrier fluid pressure to 69-70psi

3.1.6 - Secondary Extended Test Run & Commissioning of Unit

These barrier fluid pressure ranges were then implemented during an extended run of the unit whilst exporting over a twelve-hour period. During this period only minimal elevations in barrier fluid level, pressure and temperature were seen with the system equalizing at 55 degrees Celsius, allowing the system to be fully commissioned.

3.1.7 – Replacement of Agitators with New Equipment Complete

The agitator failure modes elaborated upon that were corrected by means of seal assembly modification and material upgrade, whilst successful, were not the only option to consider.

Unlike pump renewal complete, the cost of upgrading of tank agitators was not deemed prohibitive as it was far smaller, and could be included within the cost of major tank refurbishment.

The decision was taken to install new belt driven Plenty manufactured agitators where possible, as the existing Plenty manufactured units had no instances of mechanical seal failure recorded with the only faults highlighted being gear condition breakdown.

In addition to Plenty manufactured units being far more reliable, Mitchell Craig were no longer trading meaning that obtaining spare parts would be an issue going forward.

As the new Plenty units were belt driven, the gear degradation issues seen would not be a consideration going forward.

Since installation of Plenty belt driven mixers there has not been a single recorded seal, bearing, belt or any other component failure, and as such has become the preferred choice of agitator at the site.

4.0.0 – Results - Summary of Report

To summarise, the changes in condition monitoring, maintenance, data logging and the modification to plant depicted throughout the course of this report have all been targeted at proving the rotating equipment in use at Sem Logistics is safe to use considering its age.

The below areas have been the main focus:

- Intrusive condition representative data collection methods (pumps only)
- Non-intrusive condition representative data collection methods (pumps and agitators)
- Sporadic usage related failure mode correction (pumps & agitators)
- Multi product related failure mode correction (agitators only)
- Modernisation of equipment (pumps & agitators)

The success and findings of these will be critically appraised in discussion and conclusions section.

Discussion and Conclusions

The data collection methods implemented throughout this project have given a detailed insight into the condition of rotating equipment in use at Sem Logistics.

Throughout the intrusive techniques documented, it was found that the individual components within the pump sets were in most cases in serviceable condition.

The typical material loss found to wear rings and impellers allowed a conclusion to be drawn that the wear seen in these areas was almost negligible.

As these locations within the pump sets were designed to be the highest wearing area and were found to show minimal evidence of degradation, it was assumed that the wear seen in other areas was likely to be even less.

It was demonstrated as far as was reasonably practicable, that internal pump components responsible for the pumping process, should not fail through the service conditions seen at the site.

Periodic future measurement of these areas in line with routine maintenance would highlight if there was any change to the wear rates seen, and if this was found to be the case, the future pump refurbishment interval could either be extended or shortened accordingly.

The non-intrusive data collection methods allowed an in-depth insight into both pump and tank agitator condition without the need for removal from service.

Vibration analysis highlighted any equipment that showed signs of bearing degradation prior to the point where it had potential to lead to failure, allowing corrective action to be taken prior to any dangerous occurrence.

Although already a well-recognised method of measuring rotating equipment condition, the process was challenged throughout intrusive bearing defect verification, proving the information as correct.

This verification helped to further justify vibration monitoring as a reliable data collection method, and hence aided expenditure approval for the installation of the remote data gathering system on the most run pumps at the site.

This would have the benefit of giving exact bearing degradation rate going forward, and allow even more accurate predictions to be drawn on when rotating equipment may be at risk of failure.

The ultrasonic pump set investigations proved to be another useful tool in proving the hydrocarbon pump sets fitness for service.

Although not initially straightforward in regard to comparison of the data gathered, population of a large database over the course of a five-year period allowed visual representation of the data through graphing.

This graphing highlighted any clear downward thickness trends and as with the intrusive pump condition investigations, showed that almost negligible thickness loss was occurring to the pump casings in their current usage conditions.

As no thickness loss was occurring, this again allowed the frequency of these inspections to be adjusted to a much longer interval of five years as opposed to annual.

The verification of the ultrasonic data by performing further non-destructive testing when an anomaly was highlighted, helps further prove that there is a proactive approach taken to the condition monitoring of rotating equipment, and that in depth and accurate information is being gathered on the ageing plant in service.

Thermography also allowed data to be gathered without equipment being removed from service. As with vibration monitoring, thermography is a well-known non-intrusive data collection method used in industry and is very useful for justifying continued use of equipment, as it gives further insight into areas that have the potential to cause failure.

Coupled with vibration analysis, thermography allowed one of the most run pumps at the site to stay in use whilst it awaited refurbishment. Without the use of such methods, this would have ordinarily led to the unit being taken out of service, affecting the sites operation.

Through the in-depth investigations elaborated upon, it was possible to identify the seal failure modes that had become effective at the site since its transition from refinery to storage facility.

The identification of these failure modes led to their rectification through seal modification such as implementation of hydraulically balanced seals, seal face material upgrades and application of non-corroding pump shaft coatings.

This has had a positive effect on the agitator seal failure rates seen at the site with a reduction from one case per year in 2013 and 2014, with no reported cases since 2015 to present.

There was an even more positive effect apparent in regard to pump seal failure rates of six in 2013, two in both 2014 and 2015, with no reported failures throughout the course of 2016.

Modernisation of equipment was sometimes considered the best option as it meant that the condition monitoring needed to assess fitness for service of ageing plant was not initially required.

This was the case in regard to tank agitators with the cost of a complete replacement unit ranging between ten to fourteen thousand pounds depending on the size of the tank. A more modern belt drive design meant less moving components and hence less potential failure modes, meaning less maintenance required.

As the existing agitators at the site manufactured by Plenty had not had any issues with multi product service, this was used as justification for the expenditure of purchasing new units in line with major tank refurbishment. Better reliability meant less maintenance, less spare part costs, and far smaller chance of uncontrolled hydrocarbon release.

Modernisation of pumps complete was not deemed the best option in most cases due to the monetary cost. The unit that underwent fitment of a double mechanical sealing arrangement and casing irregularity non-destructive testing was an example of this, where a replacement casing alone was over 44 thousand pounds.

Due to this, it was deemed more cost effective to prove the casings integrity and lower the chance of uncontrolled hydrocarbon release through upgrade of the sealing arrangement.

The Modernisation of rotating equipment, whether through complete replacement or upgrade demonstrated that bettering seal failure rates at the site was taken seriously, and steps were constantly being taken to lower the chance these occurrences.

Based on the condition monitoring and ongoing improvements depicted throughout the course of this project, there is in depth information to support the conclusion that all reasonably practicable steps have been taken in proving that the rotating equipment in use at Sem Logistics is safe to use.

The maintenance and inspection is now performed in a manner which allows accurate predictions to be made on when a component or piece of equipment is likely to fail.

Steps are now taken to prevent such occurrences, and well-informed decisions are now taken on deciding service interval schedules and component renewal prior to failure where possible.

Recommended Further Work

Although the maintenance and condition monitoring methods highlighted upon may seem extensive and labour intensive, the intention is that through such condition monitoring, the inspection and maintenance intervals can actually be extended in some cases.

Further Agitator Maintenance and Condition Monitoring

The manufacturers guidelines for Plenty tank agitators state that the main shaft bearings should be renewed following either 100,000 hours use or every three years, depending on which occurs first. Due to the number of agitators in use at the site, carrying this out would equate to a very large expenditure inclusive of man hours and replacement bearings.

Another consideration is that such intrusive work carries a risk of uncontrolled release if performed whilst a tank is full, and due to the nature of the site this would often be the case.

It is intended that the vibration analysis surveys performed to date and going forward can be used as justification for not adhering to the manufacturers guidelines, and only renewing such bearings if there are signs of degradation present.

To date, there are a number of belt driven Plenty mixers in use at the site that have been in service for approaching nine years, and have showed no signs of bearing condition breakdown. This can be seen in Figure 32.

Figure 36 – Vibration Report Extract

West Tank Farm Mixers							
Area	Asset	Dec-16	Jun-16	Dec-15			
West Tanks	20T1A						
	20T1B						
	20T2A	3	3				
	20T2B	3	3				
	20T3A			3			
	20T3B		3				
	20T3C		3	3			
	20T4A	2					
	20T4B	3					
	20T5A	3	3	3			
	20T5B	3	3	3			
	20T6A						
	20T6B						
	20T7A	3	3	3			
	20T7B	3		3			

Dry Bearing

The mixers in use on tank 5 have been in service for 7 years and have shown no change in bearing condition, hence will not be renewed until it is highlighted that this is required.

Further Pump Maintenance and Condition Monitoring

As with the tank agitators, the purpose of carrying out the maintenance logging and analysis depicted throughout this report is not only to lessen the chances of uncontrolled hydrocarbon release.

The intention is to use the knowledge gathered throughout such investigation for performing a lesser degree of inspection and maintenance if possible.

All maintenance and inspection has a cost associated with it, whether that be man hours or the use of third parties to perform specialist inspection, hence if it can be proven that maintenance or inspection is required to a lesser degree these intervals will be extended.

Ultrasonic thickness measurement intervals are to be extended from annual to five yearly on all hydrocarbon pump sets following the end of a five-year study in September 2017, and will be further drawn out if the 5 yearly shows little or no change to the readings.

It is also the intention to extend the vibration survey interval following a five-year study if the results show an overall downward trend of equipment in fault or alert status.

If the double mechanical sealing arrangement performs as expected on the designated gasoline unit, the system will also be installed on the neighbouring pump being the same design.

Further Changes to Maintenance if Site Usage Changes

Although the condition monitoring and maintenance regime now in place on rotating equipment at the site is deemed suitable and sufficient, this may not be the case if usage conditions at the site change.

As was the case during the transition from refinery to storage facility, certain unforeseen failure modes became effective, hence if the site drastically changes the way in which it operates for any reason these systems would have to be revisited to confirm they are still effective.

Such a change could be the ever-increasing demand for bio fuels. During the investigation into the preferred elastomer for agitator sealing arrangements, the storage of Ethanol at the site was investigated.

It was found that Ethanol was potentially aggressive towards elastomers and if it was to be stored in large quantities, differing pump and agitator sealing arrangements would have to be considered.

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Appendices

Appendix 1:

Hi Joe,

Hope things are well with you. After tracking him down late last week, here are comments from my Inspection Dept contact here at Valero. He's seen the original UT, the X-ray, the Shear Wave and I mentioned you'd been able to see the internal of the casing with a camera/endscope:

I think the narrative is all good. An internal defect is present but it appears from the report to be planar and is consistent with the compression probe reading. The fact that a visual examination and crack detection has been conducted internally confirms that the defect is in the metal substrate; it's planar and has probably been there for a very long time. The good news is that this type of defect does not have any significant effect on the strength required for pressure containment (you can liken this to a laminated sheet of plywood as opposed to an equivalent size piece of timber).

Another good thing is that because it's a casting, it is significantly thicker than is required for pressure containment.

Castings can and are repaired at foundries and is a specialist task involving preheats, controlled deposition with high nickel rods and PWHT with very slow cool downs. Welding on anything with 2% carbon in a field application is like "lighting a blue touch paper" and I would definitely not consider going down this route for an item that has been in service.

A hydrotest is an ultimate proof check and is a very good thing to do.

I don't think there's much else can be done now, and I'd take his advice and not try and get it ground out / rewelded (unless it's under very controlled foundry conditions as described above).

I think there is a comprehensive set of test results available from which it can be concluded that it is an old defect, planar and is in the metal substrate, and at the size / depth it is can be expected to have minimal impact (as borne out by the length of service of the pump) and the general overdesign in metal thickness for the required pump pressure. With a successful hydrotest I'd conclude that the unit may be returned to service with minimal risk.

Best regards,

Brian Wilkinson

Senior Process Engineer

Ideas Project Engineering Ltd

Appendix 2:



Client: SEM Logistics LTD	Report No.: 1352-2711-MW2 Rev.0
Address: Waterston Road, Milford Haven, Dyfed, SA73 1DR FAO: Steve Hearn	Date of Test: 27/11/2013 Page 1 of 1 Client / Order No.: Location / Description: UT thickness and lamination survey of cast iron pump (21G86)

ULTRASONIC INSPECTION REPORT

Material:	N/a.	Surface condition:	Ground Flush
Dimensions:	Various	Limitations of test:	None
Equipment:	Sitescan 250	Serial Number:	1009270
Reference block/s:	1-10mm Step wedge	Serial Number/s:	55868
Sensitivity level:	2nd BWE to FSH	Couplant used	Sonagel

Probes used:	1	2		
Angle° / Type:	0 Twin	45 Single		
Frequency (MHz):	5	4		

Test Specification:	ASME-V: Article-5	Acceptance Standard:	Record Average thickness and map indication
----------------------------	-------------------	-----------------------------	---

Results / Notes:	Accept: ☐	Reject: ☐
An ultrasonic thickness and lamination check was carried out on pump 21G86. The area examined shows a planar indication at approximately 5-6mm depth. The readings suggest a lamination type indication 2-3mm in width. Shear wave inspection cannot confirm the quality of the material under the indication.		

Technician/s:	M Williams	Signature/s:	
Qualification/s:	PCN Level II	Certification No.:	301347
Date of Issue:	27/11/13		



Unit 2, Kingswood Trading Estate Pembroke Dock SA72 4RS T: 01646 681523 F: 01646 681523	Immingham Chatham Hull Stockton-on-Tees Website: www.irisndt.co.uk	01469 575728 01634 200283 01882 324495 01642 676001 Canada USA (780) 437-2022 (713) 722-7177 Reg. No. 2703421
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Appendix 3:



Penistone Works (UK) Ltd
Green Road
Penistone
Sheffield
S38 6JZ
Tel: +44 (0)1226 762311
Fax: +44 (0)1226 768930
Website: www.clydeunion.com

» ClydeUnion Pumps

Quotation Number: PBS 44662

Date: October 7th 2013
 Customer: SEM Logistics - Milford Haven
 Your Reference: RFQ Replacement Pump Case
 Quoted by: Sam Hall
 Pump Type: 12x12x17H CF
 Pump Serial No: B190083

Dear Mr. Edwards,

Thank you for your enquiry, please see our quotation below for your consideration.

Item	Qty	Description	Part No.	Unit Price	Line Total
1	1	Replacement Case	E01261AB11	£44,402.00	£44,402.00
<u>Inclusive of:</u> Carbon Steel Case Stub Pipework 3.1 Material Certification 2A Visual Inspection Certified Hydrotest A New Pattern Cost Factor <u>Non-Inclusive of:</u> Stuffing Box					
Total				£44,402.00	

Delivery Terms Ex-Works Penistone Plant UK
 Delivery (weeks) 20-22 working weeks (subject to confirmation at the time of purchase order)
 Payment Terms Net 30 days
 Currency GBP

- This quotation is subject to SPX standard Terms & Conditions
- Quotation valid for 60 days

We trust this quotation meets your requirements, however should you have any questions regarding this quotation please do not hesitate to contact us.



Appendix 4:



**Thermographic Survey
of
Pumps 21-G-87X and 21-G-87AX
at
SEM Logistics**

Report prepared by A. Whitcher for

J. Edwards

21/03/2017

Summary:

Two pumps in the tank farm, 21-G-87X and 21-G-87AX were examined. In general, the equipment surveyed appeared to be in good condition. No items of concern were identified. The pump bearings and motor were examined with the pumps in service. The following pages show a summary of each of the locations for each of the pumps.

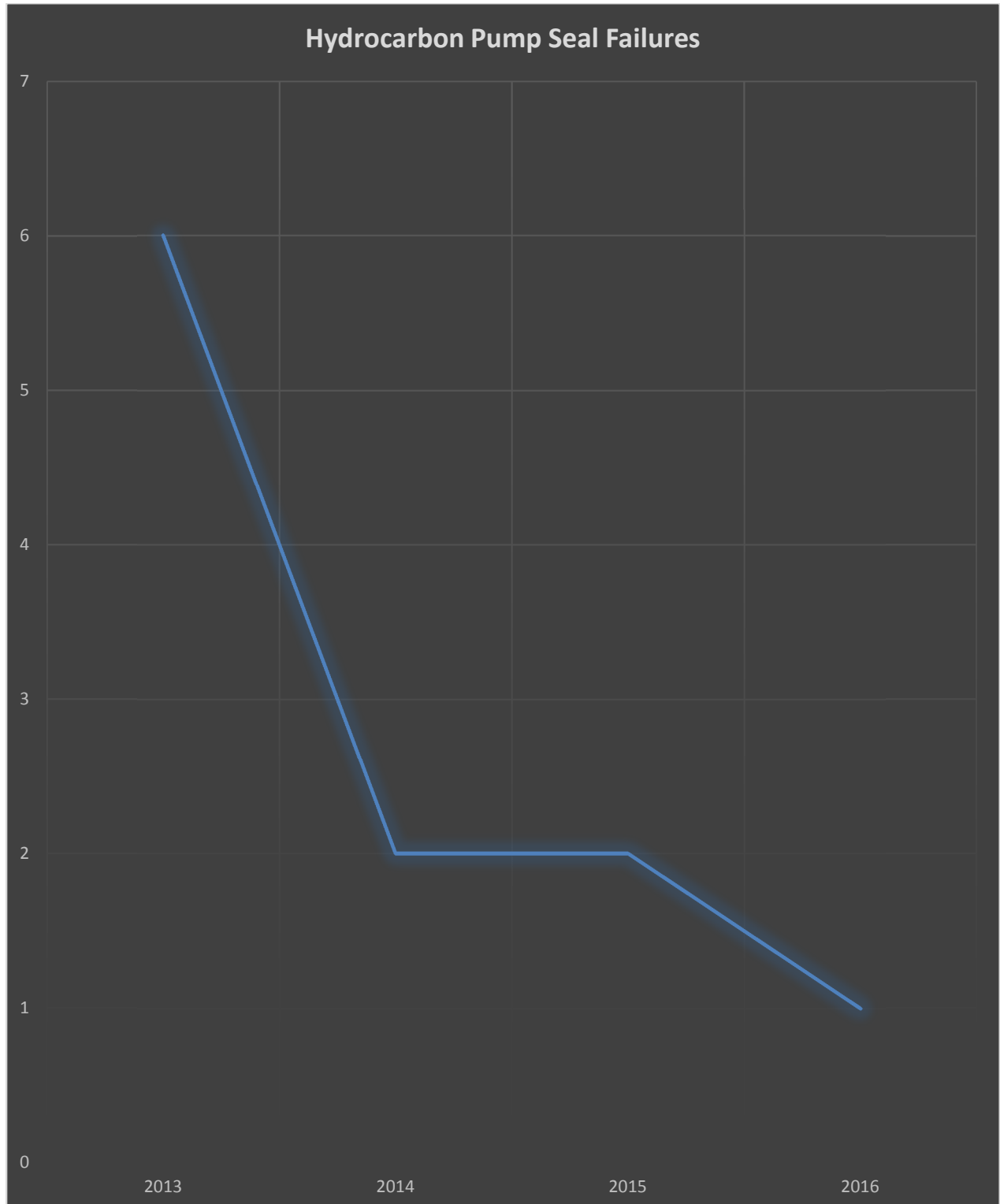
Of the two pumps, the bearings on 21-G-87AX were running at a higher temperature. The highest measured temperature (56.8°C) was on the north side of the non drive end bearing. The largest temperature difference between the pumps was for the north side of the drive end bearing, the difference was 18.9°C.

The weather conditions at the time of the survey were:

Wind direction:	Westerly
Wind speed:	3.7 m/s
Air Temperature:	8.5°C
Precipitation:	Recent light rain, however the surfaces of the bearing housings were noted to be dry.

Appendix 5:

Pump Seal Failures	2013- Jan-June	2013 Jul-Dec	2014- Jan-June	2014 Jul-Dec	2015- Jan-June	2015 Jul-Dec	2016- Jan-June	2016 Jul-Dec
Pump station 1								
21G110	0	0	0	0	0	0	0	0
21G111	0	0	0	0	0	0	2	0
21G87X	1/Refurbished	0	0	0	0	0	0	0
21G87AX	0	0	0	0	0	0	0	0
34G49	0	0	0	0	0	0	0	0



Appendix 6:

Component	Function	Failure Mode	Effects of Failure	Severity of Failure	Likelihood of Failure	Frequency of Occurrence	Detection prior to failure
Cast iron stationary sealing face	Creating sealing area against rotary seal face	Surface corrosion allowing seal seepage	Environmental implications, release of product to atmosphere, potential health risks to employees, risk of fire	1	3	3	Very small leakage may be detectable by smell
Carbon Graphite Rotary face	Creating sealing area against stationary seal face	'Ringling' of faces can cause the material to tear	Environmental implications, release of product to atmosphere, potential health risks to employees, risk of fire	3	2	2	It is not possible to determine whether the faces have 'rung' together without disassembling the plant
Silicon Carbide stationary sealing face	Creating sealing area against rotary seal face	Identical grade Silicon Carbide to rotary face can cause seal seepage	Environmental implications, release of product to atmosphere, potential health risks to employees, risk of fire	1	2	1	Very small leakage may be detectable by smell
Rubber bellows	Provide friction drive rotary sealing face	Misshaping or distortion caused by range of product service	Environmental implications, release of product to atmosphere, potential health risks to employees, risk of fire	2	3	3	Smaller leakages may be detectable by smell

Current Process Controls	Risk Priority Number	Recommended Actions	Actions Taken	New severity of Failure	Likelihood of Failure	Frequency of Occurrence	New Risk Priority Number
Look, listen, feel assessment performed by operator upon start up and throughout use of equipment	9	Change to a material that does not corrode	Stationary face changed to Silicon Carbide material	1	1	1	1
Look, listen, feel assessment performed by operator upon start up and throughout use of equipment	12	Change to a material of higher shear strength	Rotary face changed to Silicon Carbide material	3	1	1	3
Look, listen, feel assessment performed by operator upon start up and throughout use of equipment	2	Change Rotary seal face material to differing grade of Silicon Carbide	Rotary face of differing Silicon Carbide grade installed	1	1	1	1
Look, listen, feel assessment performed by operator upon start up and throughout use of equipment	12	Change bellows to a material that doesn't mishape or degrade in a range of product services	Changed material of bellows from Nitrile to Viton	2	1	1	2

Appendix 7:

Product Design Specification

Performance

- Any changes to mechanical seal component(s) must eliminate or minimise occurrence of hydrocarbon containment loss - Out of seventy mixers in use, failure rates prior to design change circa one failure on the site per month
- Any change in mechanical seal components decided upon must be capable of dealing with a range of product service
- Any change in mechanical seal components decided upon must be capable of dealing with periods of inactivity – May be inactive between 1-12 months depending on tank service

Design

- Any changes to design of any component must eliminate or minimise instances of hydrocarbon containment loss
- Any changes to design must fully address service conditions before their implementation
- There must be a benefit to the design change in order to justify its implementation – i.e. improved lifetime, less occurrences of failure, less down time due to failure

Materials

- Any changes of material specification of any component must eliminate or minimise instances of hydrocarbon containment loss
- Any changes of material specification of any component must fully address service conditions before their implementation – A range of product service is highly likely
- There must be a benefit to the material change in order to justify its implementation – Harder wearing, improved lifetime, less occurrences of failure, less down time due to failure

Standards

- The seal assembly shall apply to all applicable standards in regard to mechanical sealing systems – API 682 and Fluid Sealing Association
- The seal must modernise the existing system and demonstrate a forward move in bettering maintenance strategies at the site – i.e. less seal failure, levels prior to design change were circa twelve failures per year from seventy mixers in use (Circa 17% failure rate per annum)

Safety

- The assembly must look to improve safety i.e. personnel in contact with the equipment
- Any changes to the assembly must lead to an improvement on emissions to environment

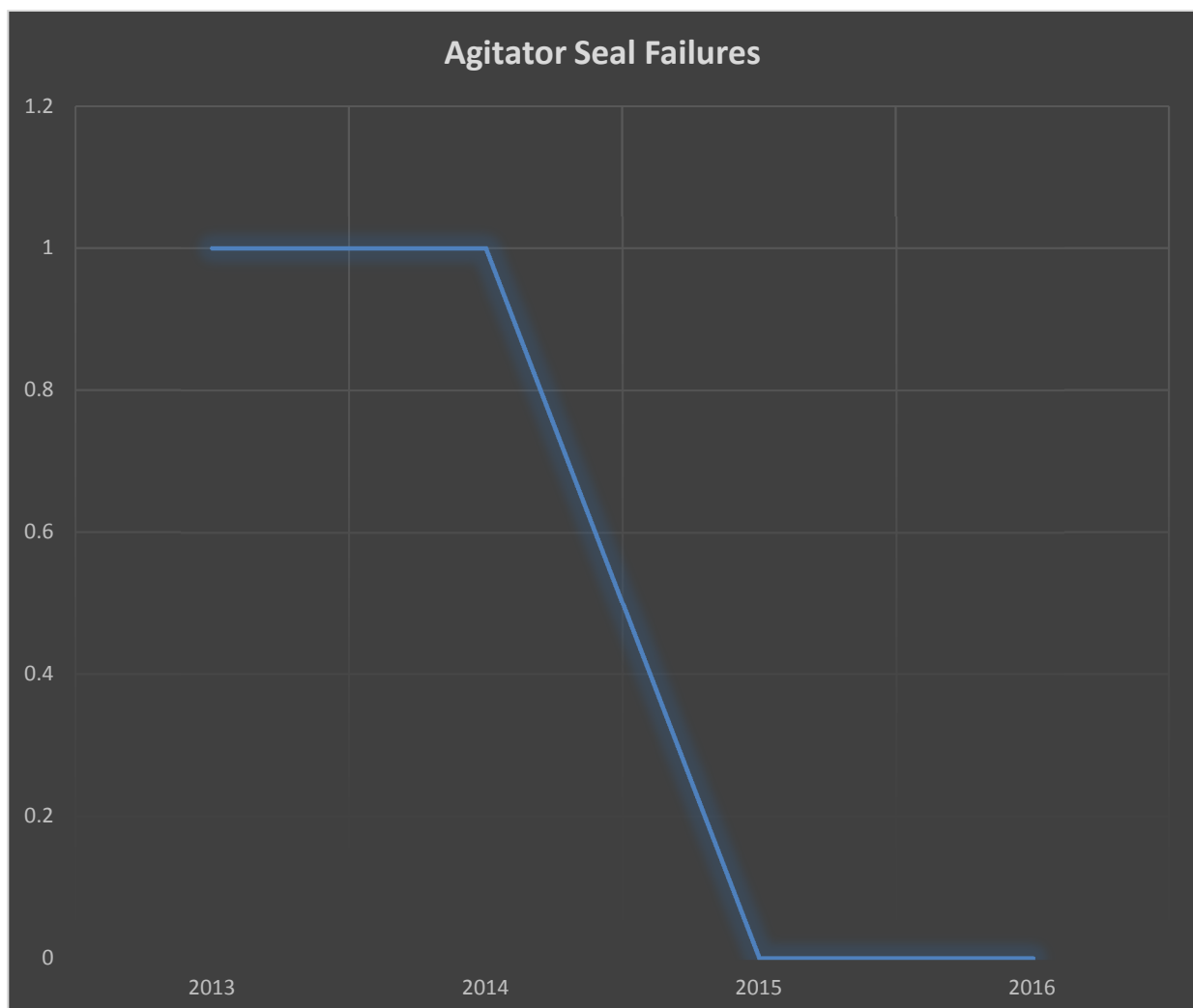
Design life

- The new system used must have a longer design life than the currently implemented system – Current failure is at least once every 5 years, this needs to be improved upon
- The new system needs to be installed with the intention it will wear out before requiring changing, as opposed to component failure leading to premature removal from service – Minimum 5 years' service

Appendix 8:

Tank Mixer Seal Failure	2013- Jan-June	2013 Jul-Dec	2014- Jan-June	2014 Jul-Dec	2015- Jan-June	2015 Jul-Dec	2016- Jan-June	2016 Jul-Dec
West Tankage								
Tank 1 A	0	0	0	0	0	0	0	0
Tank 1 B	0	0	0	0	0	0	0	0
Tank 2 A	0	0	0	0	0	0	0	0
Tank 2 B	0	0	0	0	0	0	0	0
Tank 3 B	0	0	0	0	0	0	0	0
Tank 3 C	0	0	0	0	0	0	0	0
Tank 4 A	0	0	0	0	0	0	0	0
Tank 4 B	0	0	0	0	0	0	0	0
Tank 5 A	0	0	0	0	0	0	0	0
Tank 5 B	0	0	0	0	0	0	0	0
Tank 6 A	0	0	0	0	0	0	0	0
Tank 6 B	0	0	0	0	0	0	0	0
Tank 7 A	0	0	0	0	0	0	0	0
Tank 7 B	0	0	0	0	0	0	0	0
Tank 8 A	0	0	0	0	0	0	0	0
Tank 8 C	0	0	0	0	0	0	0	0
Tank 9 B	0	0	0	0	0	0	0	0
Tank 9 C	0	0	0	0	0	0	0	0

Key		
Least preferred seal arrangement or seal arrangement unknown		Michell Craig with old seal
Low risk seal arrangement		Gear driven plenty
Medium risk seal arrangement		Michell Craig with preferred seal arrangement
Preferred seal arrangement		New mixers belt driven
Change with mixer		Change with mixer see note for details
Seal Failure		Seal failure of any sort



Appendix 9:

ideas Project Engineering Ltd Technical Resourcing	REPORT	
PROPRIETARY	21-G-86 DOUBLE MECHANICAL SEAL SYSTEM RECOMMENDATIONS	1695-REPT-SEM-53-0082

1 Introduction

This document summarizes the recommendations made with respect to upgrading the existing single mechanical seal fitted to 21-G-86 Gasoline Pump at the SemLogistics Milford Haven facility.

This is a separate topic to the recent inspection of this pump and the conclusions made following those activities as regards returning the pump to operations in a 'fit-for-service' condition.

2 Background

21-G-86 has been in service on gasoline and other similar low flashpoint hydrocarbon service for in excess of 30 years, and in common with equipment from that time is fitted with a single mechanical seal arrangement.

Current best practice for such pumps would be to employ a double seal arrangement, so as to provide an enhanced level of protection against a significant spill of material via seal failure.

With 21-G-86 currently subject to inspection / overhaul there is a window of opportunity to install double seals.

3 Technical Recommendations**3.1 General / API Plan Arrangement**

Following discussions with experienced rotating equipment engineers, a double mechanical seal conforming to API seal plan 53A (dual, pressurised with liquid barrier fluid) is recommended. This arrangement are suitable for higher vapour pressure light hydrocarbons at the pressures in question (up to around 10 barg / 150 psig) and allow isolation of the process fluid and no leakage to atmosphere (unless the barrier fluid pot pressure is lost and the vent is left open).

A plan 74 (dual pressurised gas seal) would also be technically acceptable but would require a permanent utility (gas) supply which is probably less convenient for a tank farm location.

3.2 Keypoints: Specification / Installation

Keypoints that should be followed in the detailed specification and installation of the system are as follows:

- a. It should comply with API 682 / ISO 21049 'Pump – Shaft-sealing Systems for Centrifugal and Rotary Pumps'

	REPORT	
PROPRIETARY	21-G-86 DOUBLE MECHANICAL SEAL SYSTEM RECOMMENDATIONS	1695-REPT-SEM-53-0082

- b. The Vendor should also provide the associated barrier fluid reservoir and instrumentation, which is typically mounted on a frame that can be located close to the pump. This system should include per API 682:
- A low pressure switch
 - A local pressure gauge
 - A low level switch.
 - A field level gauge
 - Separate valved connections for reservoir refill (barrier fluid) / pressurisation, reservoir vent and reservoir drain
 - A high level switch is desirable, but not mandatory

The Vendor will need to specify any utility (cooling) requirements for the seal fluid.

Note that nitrogen is required for pressurisation, but is easily provided via a cylinder positioned locally and fitted with suitable pressure regulator and no permanent supply is needed.

- c. Since the low pressure and low level switch serve to flag leakage into the inner seal as well as out of the outer seal, it is strongly recommended that these be alarmed to the Control Room (a common alarm would suffice). If this is not achievable, then, as a minimum, local alarm provision should be provided together with prescribed Operator checks on a frequent basis when the pump is in operation.
- d. The Vendor should be engaged to fit (or Supervise fitting of) the new seal arrangement at SemLogistics and approve the seal system installation as ready for service.

It would also be desirable for the Vendor representative to be present at Site when the pump is first returned to service in order to

- verify that the installation (tubing) between the seal and the reservoir is properly installed (note that correct relative elevations between reservoir and seal inlet / outlet ports, and tubing slopes are important)
 - advise Operations staff on proper pre-check and start-up procedures.
- e. With this seal plan, there is a very small leakage of barrier fluid across the seal and into the product over time. The barrier fluid should be compatible with the fluid pumped. In practice this should not be an issue since barrier fluids are commonly hydrocarbon-based.

Appendix 10:

SEMLogistics Ltd. is a marine-fed crude oil and petroleum products storage terminal in Milford Haven, Pembrokeshire. The terminal has more than 50 aboveground storage tanks, with their associated pipework and pumping systems. Products stored include gasoline, gasoline blendstocks, naphtha, jet fuel, gas oil and diesel, as well as crude oil.

A number of pump rafts exist across the terminal for inter-tank transfers and exports to marine vessels. In response to concerns regarding possible leaks of gasoline from shaft seals, a double mechanical seal has been fitted to gasoline pump 21G-86 at pump raft P5¹. The seal fluid reservoir is fitted with pressure and level switches giving indication of low pressure and low level.

Given the highly flammable nature of gasoline, an assessment has been performed to determine the risks associated with failure of the seal, and whether it is necessary for the instrumentation associated with the seal reservoir to be SIL rated.

Risk Assessment:

A risk assessment meeting was held on November 3rd 2016 at SEMLogistics Milford Haven, and focussed on the causes of failure of the double mechanical seal, and the safeguards already in place. This meeting is recorded in Appendix 1.

The risk assessment meeting identified the major hazardous consequence of seal failure and listed the safeguards already included in the design of the system.

Severity of Consequences:

The severity of the consequences of the hazards identified is judged against the following scale:

Severity	Personal Consequence	Business Consequence
Catastrophic	Multiple fatalities on site. Single death off site Severe widespread environmental impact	Gross media interest and adverse publicity Cost of damages greater than funds available to the business.
Critical	Single fatality or Multiple severe injuries or Occupational illnesses on site Injury or illness off site Environmental impact off site	Public interest requiring management brief to the media Cost to company up to £1,000,000 Down time less than 12 weeks
Serious	Single severe injury or Occupational illness or Multiple minor injuries on site	Cost to company up to £100,000 Down time less than six weeks
Minor	Minor injury (Short term absence)	Cost to company up to £10,000 Down time less than two weeks
Negligible	Trivial injury (First aid only)	Cost to company insignificant. Down time less than one week.
Normal Operation	No injury	No cost to company

Frequency of Causes

The likelihood of the deviation or failure resulting in a hazard is judged against the following scale.

Frequency	Per year	Definition / Examples
Frequent	1-10	Often occurs with this type of operation
Probable	10^{-1} -1	Can be expected reasonably often
Occasional	10^{-2} - 10^{-1}	Can be expected to occur sometime Leak from primary containment Failure to follow every day instructions Failure of normal instrumentation Failure of normal industrial equipment
Remote	10^{-3} - 10^{-2}	Could be expected to occur in system life Failure of basic process control system Failure to follow annual instructions Combination of human errors
Improbable	$< 10^{-3}$	Rare, but may occur sometime in system life Catastrophic failure of metallic component Operator error in combination with equipment failure Failure of two independent mechanical systems

Risk Matrix

The combination of the severity of the hazard and the frequency of its occurrence are combined using the following table to give the resulting risk level.

	Frequent	Probable	Occasional	Remote	Improbable
Catastrophic	Very High Risk	Very High Risk	Very High Risk	High Risk	Medium Risk
Critical	Very High Risk	Very High Risk	High Risk	Medium Risk	Low Risk
Serious	Very High Risk	High Risk	Medium Risk	Low Risk	Broadly Acceptable
Minor	High Risk	Medium Risk	Low Risk	Broadly Acceptable	Broadly Acceptable
Negligible	Medium Risk	Low Risk	Broadly Acceptable	Broadly Acceptable	Broadly Acceptable
Normal Operation	Broadly Acceptable	Broadly Acceptable	Broadly Acceptable	Broadly Acceptable	Broadly Acceptable

Assessment of Consequences

The consequences arising from the loss of containment from the double mechanical seal was assessed by the team. The most likely serious event was considered as the generation of a spray of gasoline and its associated flammable cloud of mist and vapour, followed by ignition, and death of any personnel in the vicinity of the ignited cloud.

HSE guidanceⁱⁱ for spray releases likely from mechanical seal failure suggest a 50µm crack around the circumference of the shaft. In this case, the shaft is 3" (76.2mm) diameter, giving an opening with a total area of 12mm², i.e. a mean diameter of 3.9mm.

Table C4 of EI15ⁱⁱⁱ gives a hazardous area radius of 21m for a release of a Category C fluid (such as gasoline) from a 5mm diameter hole with a pressure of 10 bara. Using methods from SIRA^{iv}, this can be reduced to 15m when the maximum pressure of 120psig (9.3bara) is applied to the hole area. This assumes that the entire leak of gasoline forms a flammable vapour cloud / mist, with no allowance for rain out.

The area within the flammable cloud is relatively uncongested, with a large part extending onto 9th Street, immediately to the east of P5, and the remainder extending under track TD and the area between P5 and the 600 Series Bund.

It is recognised that it is relatively unlikely to have detonation in a fuel-air cloud originating from an accidental release in the open. Applying the decision tree of Cates^v, it is reasonable to assume an overpressure in the vapour cloud of 0.2bar. With this source strength, the closest storage tanks (Tk600 and Tk605, some 40m distant) will experience an overpressure of 0.06bar which, while significant, is unlikely to cause tank failure. Alternatively, applying the Yellow Book^{vi} methodology, a blast of this type with a low ignition energy, low levels of obstruction and unconfined combustion, a source strength of 0.05bar is estimated in the vapour cloud.

Thus, it is reasonable to assume that a spray release from the pump seal, followed by ignition will result in an unconfined deflagration with minimal blast effects: the more significant consequences will be from thermal radiation and burns for any personnel in the vicinity at the time of ignition.

Assessment of Frequency

Pump Failure

HSE guidance^{vii} as to the frequency of the failure of double mechanical seals from all causes give a "spray release" frequency of 5×10^{-5} per pump per year.

SEM report a maximum utilisation of any pump on site as being 15%, equivalent to 1314 hours per year. Applying this to the spray release frequency gives a modified frequency of a spray release from failure of the mechanical pump seal of as 7.5×10^{-6} per pump per year.

Ignition Source

Since the field operator visits the pump at regular intervals and drives a vehicle with an internal combustion engine to Pump Raft P5, a probability of ignition of 0.1 has been assumed, consistent with Table C10 of IE15^{viii} for a medium strength ignition source (road traffic, hot surfaces, engines etc.). This gives a risk of ignition of the vapour cloud arising from pump seal failure as 7.5×10^{-7} per pump per year.

Time at Risk

The field operator is at risk during the periodic checks of the pump, approximately every 2 hours. In the event of a seal failure, it will continue until discovered – i.e. until the next scheduled check. In the event of a leak, it has been assumed that it is certain that the field operator will arrive at the next scheduled check and place himself within the hazardous area.

Thus, the frequency of a spray leak from the pump mechanical seal followed by ignition in the presence of the field operator is 7.5×10^{-7} per pump per year.

Risk Assessment:

Using the matrix above, the severity of the consequence (i.e. a single fatality) is “Critical” and the frequency (7.5×10^{-7} per pump per year) is “Improbable”, giving a “Low Risk”. Even if all pumps across the terminal were considered, the individual risk to a field operator would be less than 10^{-5} per year, and the risk would remain “Low Risk”.

NB: The matrix is constructed such that a “Critical” consequence can never fall into the “Broadly Acceptable” risk category, and so will always result in a “Low Risk” unless the consequences can be reduced.

Conclusions and Recommendations:

This risk assessment shows that a spray release from the pump seal, followed by ignition will result in an unconfined deflagration with minimal blast effects: the more significant consequences will be from thermal radiation and burns for any personnel in the vicinity at the time of ignition.

The unmitigated frequency of a spray leak from the pump mechanical seal followed by ignition in the presence of the field operator is 7.5×10^{-7} per pump per year. If all pumps on site are considered, the individual risk of death to a field operator is less than 10^{-5} per year.

This combination of severity (“Critical”) and frequency (“Improbable”) presents an unmitigated “Low Risk” from pump seal failure.

The risk assessment identified several operating procedures and instrument alarms with operator action that further reduce the likelihood of a spray release from pump seal failure.

However, the nature of the risk matrix is such that these risk reductions only affect the frequency and so do not change the outcome: the residual risk remains “Low Risk”.

This would be the case even if the instrumentation associated with the seal was to form part of a Safety Instrumented System.

The following actions arose from the risk assessment meeting:

Action No	Action	On
1	Ensure operating procedures include details of action to be taken if seal pot low level alarms.	SEM
2	Ensure operating procedures include details of action to be taken if seal pot low pressure switch alarms.	SEM
3	Establish correct operating pressure of seal pot following commissioning tests.	SEM
4	Consider operational or PM check of remaining pressure in compressed air bottle.	SEM
5	Check hygroscopicity of barrier fluid (Thermotec 15 heat transfer oil), and whether more frequent changing is justified.	SEM
6	Consider tagging and sealing the regulator to prevent tampering.	SEM
7	Consider installation of coarse in-line strainers ("witches' hats") in pump suction pipework.	SEM
8	Include seal pot level in pump start-up checks and periodic checks while running.	SEM

Appendix 11:

I'm not going to be here when 21G86 runs tomorrow, not ideal I know but this may be one of the last chances we have to test run this unit.

Can we please ensure the following is adhered to:

- If the discharge pressure is 85psi, please set the barrier fluid to 66psi
- If the discharge pressure is 90psi, please the barrier fluid pressure to 67-68psi
- If the discharge pressure is 95psi, please set the barrier fluid pressure to 68-69psi
- If the discharge pressure is 100psi, please set the barrier fluid pressure to 69-70psi

Summarising the guidance from AES seals, if the above is adhered to we should expect to see a barrier fluid vessel temperature of around 56 degrees Celsius, although this may rise slightly and then equalise.

If the temperature stabilises at circa 56 degrees, we should not expect to see the large elevations in barrier fluid level and pressure as we did last time, I'd expect the barrier fluid system to meet some sort of equilibrium in respect to all three of these, (temp, level and pressure).

I would expect to see some elevation in all these from initial start up to the point of equilibrium, so please closely monitor the unit for the first couple of hours of running, or until the point where it seems equilibrium has been reached.

I'll talk to Malcolm Evans today and have him attend when the unit is started up, and for the first couple of hours of running.

For reference: elevations in these levels the last time the pump was run: temp: nearing 70+ degrees, level: 25mm increase from starting point, Pressure: 50psi increase from starting pressure, so I would expect smaller increases in all of these this time.

Steve Salter & Blackham, please let me know if you don't agree with any of the above.

Many thanks

Joe Edwards

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<image001.png>

DRIVE SUCCESS

"Our philosophy isn't about bracing for the future, it's about driving it."

From: Steve Blackham [mailto:steve.blackham@aes seal.co.uk]

Sent: 10 March 2016 14:52

To: Edwards, Joe <jedwards@SEMGROUPCORP.COM>

Cc: Dow, Jamie <jdow@SEMGROUPCORP.COM>; Coleman, Charlie <ccoleman@SEMGROUPCORP.COM>; Price, Dave <dprice@SEMGROUPCORP.COM>; Scott, Andrew <ascott@SEMGROUPCORP.COM>; Pettit, Simon <SPettit@SEMGROUPCORP.COM>; Mathias, John <jmathias@SEMGROUPCORP.COM>; steve.salter@aes seal.co.uk

Subject: Re: Batcalc results

Joe

Conquer with your assessment. Hope all goes well tell your guys if they need to contact me no problem on 07775821428 or 07894439087

Steve Blackham
Sent from my iPhone

On 10 Mar 2016, at 13:29, Edwards, Joe <jedwards@SEMGROUPCORP.COM> wrote: